5-30-2014

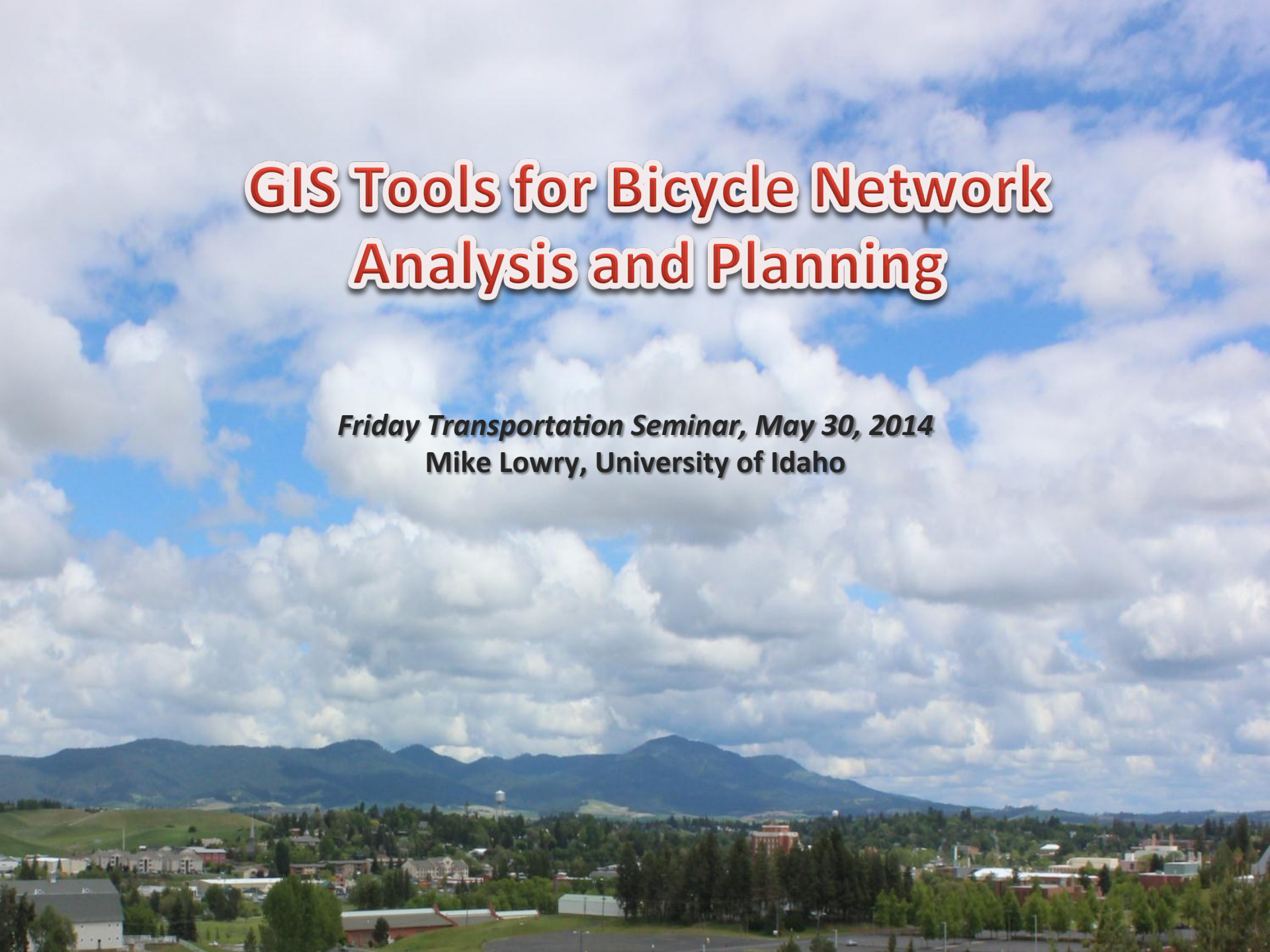
GIS Tools for Bicycle Network Analysis and Planning

Mike Lowry
University of Idaho

GIS Tools for Bicycle Network Analysis and Planning

Friday Transportation Seminar, May 30, 2014

Mike Lowry, University of Idaho

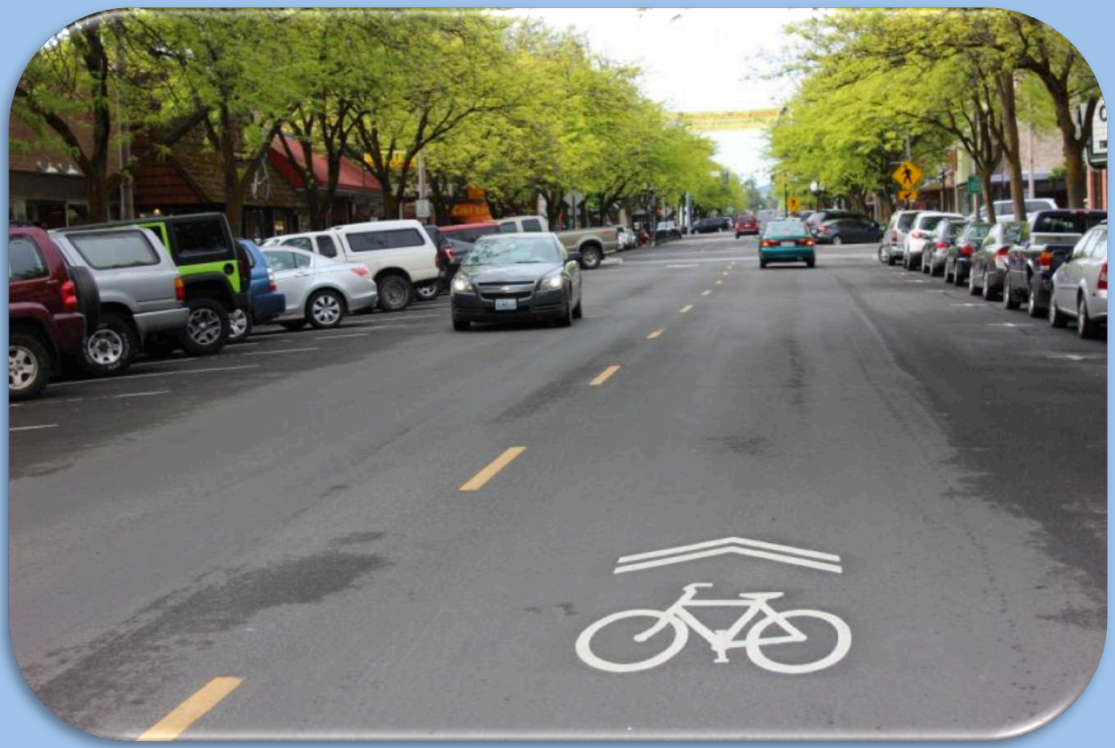


Tool 1: Calculate Bicycle Level of Service

Tool 2: Calculate Community-wide Bikeability

Tool 3: Estimate Bicycle Volumes

Tool 4: Assess Dangerous Situation Exposure



Tool 1

CALCULATE BICYCLE LEVEL OF SERVICE

Background

- **Bicycle Suitability**

  Perceived comfort and safety of a segment of street or pathway

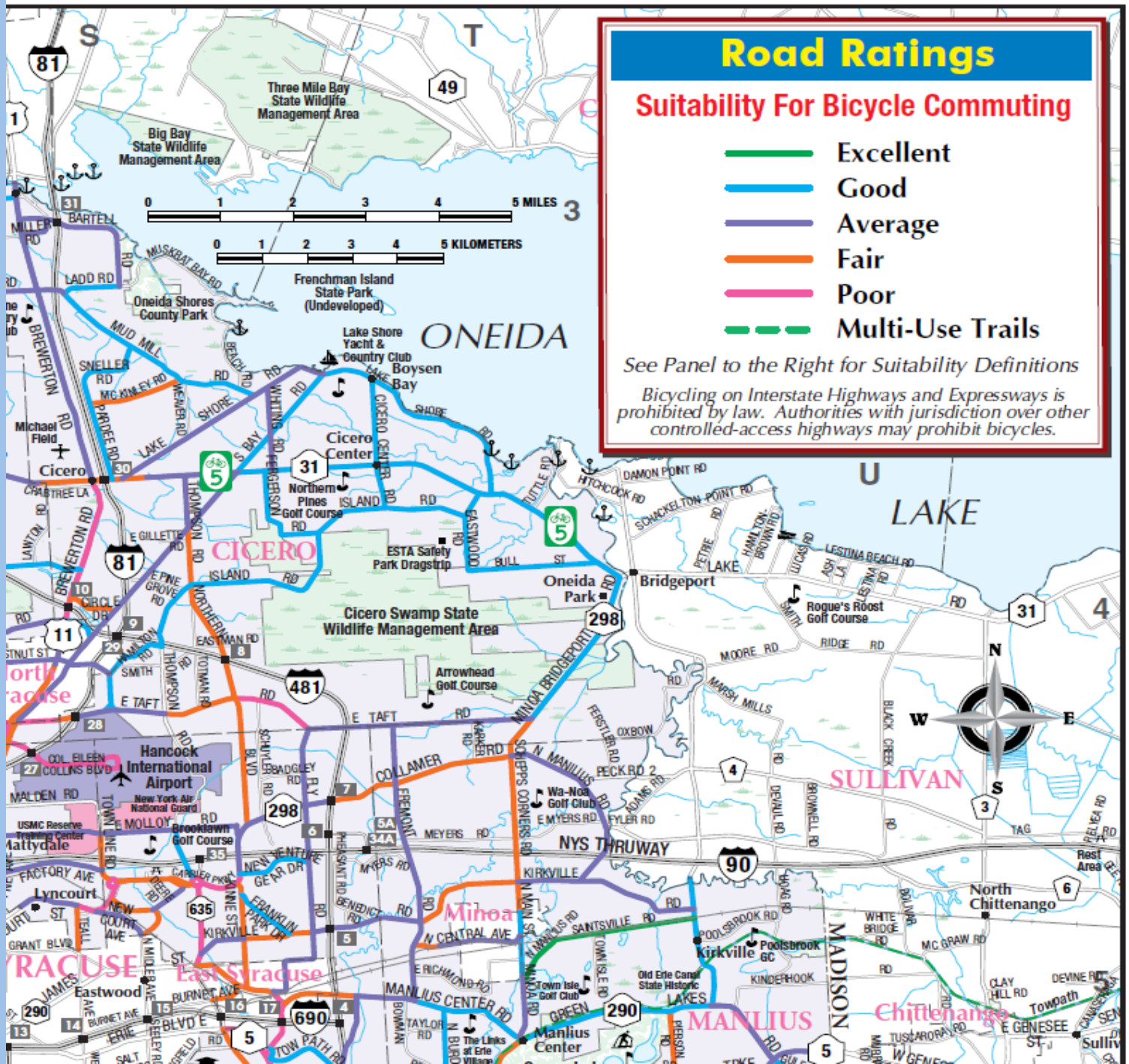
- **Bikeability**

  Perceived comfort and safety of network connectivity for accessing important destinations

- **Bicycle Friendliness**

  Perceived comfort and safety of all aspects of bicycle travel, including bikeability, laws and policies to promote bicycling, education efforts to encourage bicycling, and general acceptance of bicycling throughout the community

Name of Method	Acronym	Author	Date
Bicycle Safety Index Rating	BSIR	Davis	1987
Bicycle Stress Level	BSL	Sorton and Walsh	1994
Road Condition Index	RCI	Epperson	1994
Interaction Hazard Score	HIS	Landis	1994
Bicycle Suitability Rating	BSR	Davis	1995
Bicycle Level of Service	BLOS	Botma	1995
Bicycle Level of Service	BLOS	Dixon	1996
Bicycle Suitability Score	BSS	Turner et al	1997
Bicycle Compatibility Index	BCI	Harkey et al	1998
Bicycle Suitability Assessment	BSA	Emery and Crump	2003
Rural Bicycle Compatibility Index	RBCI	Jones	2003
Compatibility of Roads for Cyclists	CRC	Noel et al	2003
Bicycle Level of Service	BLOS	Zolnik	2007
Bicycle Level of Service	BLOS	Jensen	2007
Bicycle Level of Service	BLOS	Petritsch et al	2007
Bicycle Environmental Quality Index	BEQI	SFDPH	2009
Bicycle Quality Index	BQI	Birk et al	2010
Bicycle Level of Service	BLOS	HCM	2011
Bicycle Levels of Traffic Stress	LTS	Mekuria and Furth	2012
Protected Lane Level of Service	PL-LOS	Foster and Monsere	Today


Road Ratings
Suitability For Bicycle Commuting
Excellent
Good
Average
Fair
Poor
Multi-Use Trails
See Panel to the Right for Suitability Definitions
Bicycling on Interstate Highways and Expressways is prohibited by law. Authorities with jurisdiction over other controlled-access highways may prohibit bicycles.
ONEIDA
LAKE
SULLIVAN
MADISON
MANLIUS
CICERO
SYRACUSE
East Syracuse
Minoa
Chittenango
North Chittenango
Three Mile Bay State Wildlife Management Area
Big Bay State Wildlife Management Area
Frenchman Island State Park (Undeveloped)
Oneida Shores County Park
Lake Shore Yacht & Country Club
Boysen Bay
Cicero Center
Northern Pines Golf Course
ESTA Safety Park Dragstrip
Cicero Swamp State Wildlife Management Area
Arrowhead Golf Course
Oneida Park
Bridgeport
Rogue's Roost Golf Course
Hancock International Airport
New York Air National Guard
USMC Reserve Training Center
Brooklawn Golf Course
Wa-Nee Golf Club
Kirkville
Poolsbrook GC
Town Isle Golf Club
Old Erie Canal State Historic
The Links at Erie Village
Manlius Center
Michael Field
Lyncourt
Eastwood
Mattydale
Cicero
Rest Area
NYS THRUWAY
0 1 2 3 4 5 MILES
0 1 2 3 4 5 KILOMETERS

Attribute	Method				
	BSL	BSS	BCI	BSA	BLOS
width of outside lane	x	x	x	x	x
width of bike lane			x	x	x
width of shoulder		x	x	x	x
on-street parking			x	x	x
presence of curb				x	x
vehicle traffic volume	x	x	x	x	x
number of lanes				x	x
speed limit	x	x	x	x	x
percent heavy vehicles			x		x
pavement condition		x		x	x
elevation grades				x	
adjacent land use			x	x	
storm drain grate				x	
physical median				x	
turn lanes			x	x	
frequent curves				x	
restricted sight distance				x	
numerous driveways				x	
presence of sidewalks				x	

Equation

$$\textit{Bicycle Level of Service} = 0.76 + [-0.005((w_{ol} + w_{bl} + w_{os})(2 - 0.005v) + (w_{bl} + w_{os} - 20p_{pk}) - 1.5c)^2] + 0.507 \ln\left(\frac{v}{4N_{th}}\right) + 0.199[1.119 \ln(S - 20) + 0.8103](1 + 0.1038P_{HV})^2 + 7.066\left(\frac{1}{P_c^2}\right)$$

Input

Attribute	Description
wol	width of outside lane (ft)
wbl	width of bike lane (ft)
wos	width of outside shoulder including parking and gutter (ft)
ppk	estimated proportion of on-street parking that would be occupied during analysis period (decimal)
c	curb present (yes = 1, no =0)
v	directional analysis period vehicle volume (vph)
Nth	number of through lanes (#)
S	average vehicle speed (mph)
PHV	percent heavy vehicles (decimal)
Pc	pavement condition (poor-excellent) (0-5)

Output

BLOS	Letter Grade
≤ 2.00	A
2.00-2.75	B
2.75-3.50	C
3.50-4.25	D
4.25-5.00	E
>5.00	F

Equation

$$\text{Bicycle Suitability Score} = \text{Traffic Volume Factor Score} + \text{Shoulder Width Factor Score} + \text{Speed Limit Factor Score} + \text{Pavement Factor Score}$$

Input

Traffic Volume (ADT per lane)	Shoulder Width [If no shoulder, Curb Lane Width] (ft)	Speed Limit (mph)	Pavement Condition (HPMS rating)	Factor Score
≤ 1,000	≥ 6 [≥ 15]	≤ 40	4-5	2
1,000-1,999	4-6 [14-15]	49-50	3-4	1
2,000-4,999	2-4 [12-14]	50-59	3	0
5,000-9,999	0-2 [12]	60-69	2-3	-1
≥ 10,000	0 [≤ 12]	≥ 70	1-2	-2

Output

Score Range	Interpretation
6 to 8	All four suitability factors have greater than minimum desirable values. The physical characteristics of the roadway are most likely desirable by intermediate to experienced bicyclists.
-1 to 5	At least three of the four suitability factors have minimum desirable or greater than minimum desirable values. One suitability factor may have less than desirable values. The physical characteristics of the roadway could be desirable by intermediate to experienced bicyclists.
-2 to -5	At least two of the four suitability factors have less than minimum desirable values. One or two of the suitability factors may have minium desirable values. The physical characteristics of the roadway may not be desirable by intermediate to experienced bicyclists.
-6 to -8	All four of the suitability factors have less than the minimum desirable values. The physical characteristics of the roadway are most likely undesirable by intermediate to experienced bicyclists.

Intended for state highways and intermediate or experienced bicyclists.

Date: April 4, 2002	Comments/Suggested Improvements:
Data Collector Name: Jim	**BICYCLE SUITABILITY ASSESSMENT**
Segment ID Number/Name: 101 - Sample	
Boundary streets: Walnut / Tulip	

A) General Road Factors	Measures
1) Annual Avg. Daily Traffic (AADT)	16,500
2) Total number of through lanes	2
3) Speed (mph)	35
4) Outside lane width (e.g., 11.5')	12.5
5) Bike lane or paved shoulder width (e.g., 4.5') (Note - a **marked** bike lane.)	Ø

Record these measures in the formula below

B) Pavement Factors	Score
1) (*circle one pavement description*)	(*record score*)
Very Good = 0.25	
Good = 0.75	0.75
Fair = 1.50	
Poor = 2.25	
Very Poor = 3.75	
2) Presence of a Curb (Y) N	Yes = 0.25
3) Rough RR Crossing Y (N)	Yes = 0.50
4) Storm Drain Grate (Y) N	Yes = 0.75
TOTAL Scores *Record score in formula below*	1.75

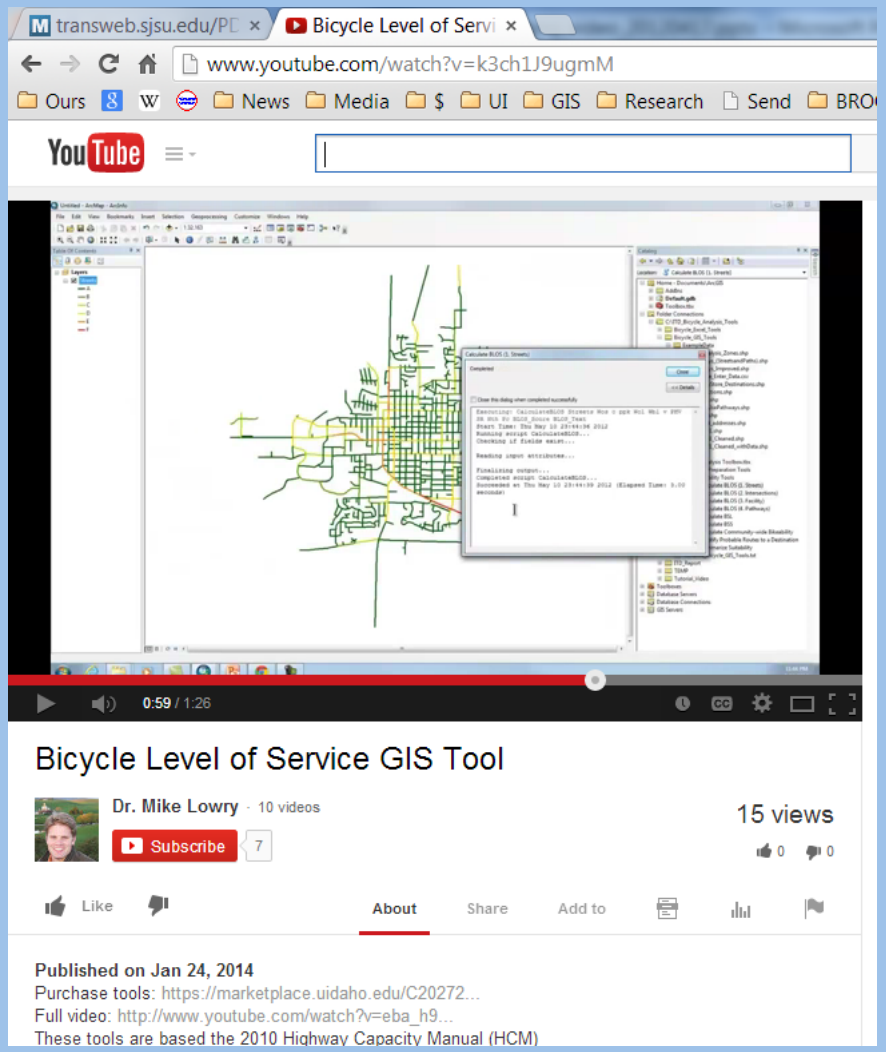
C) Location Factors	Yes/No (*circle*)	Score for "Yes"
1) Angle Parking	Y (N)	0.75
2) Parallel Parking	(Y) N	0.50
3) Right-Only Turn Lanes	(Y) N	0.25
4) Center (Both)Turn Lane	Y (N)	-0.25
5) Physical Median	Y (N)	-0.50
6) Paved Shoulder	Y (N)	-0.75
7) Marked Bike Lane	Y (N)	-1.00
8) Severe Grades	Y (N)	0.50
9) Moderate Grades	(Y) N	0.25
10) Frequent Curves	(Y) N	0.25
11) Restricted Sight Distance	(Y) N	0.50
12) Numerous Driveways	(Y) N	0.50
13) Numerous Intersections	Y (N)	0.75
14) Difficult Intersections	Y (N)	1.00
15) Industrial Land Use	Y (N)	0.50
16) Commercial Land Use	(Y) N	0.25
17) Sidewalk Only One Side	(Y) N	0.25
18) Sidewalks do not exist	Y (N)	0.50
TOTAL all "YES" points *Record score in formula below*		2.75

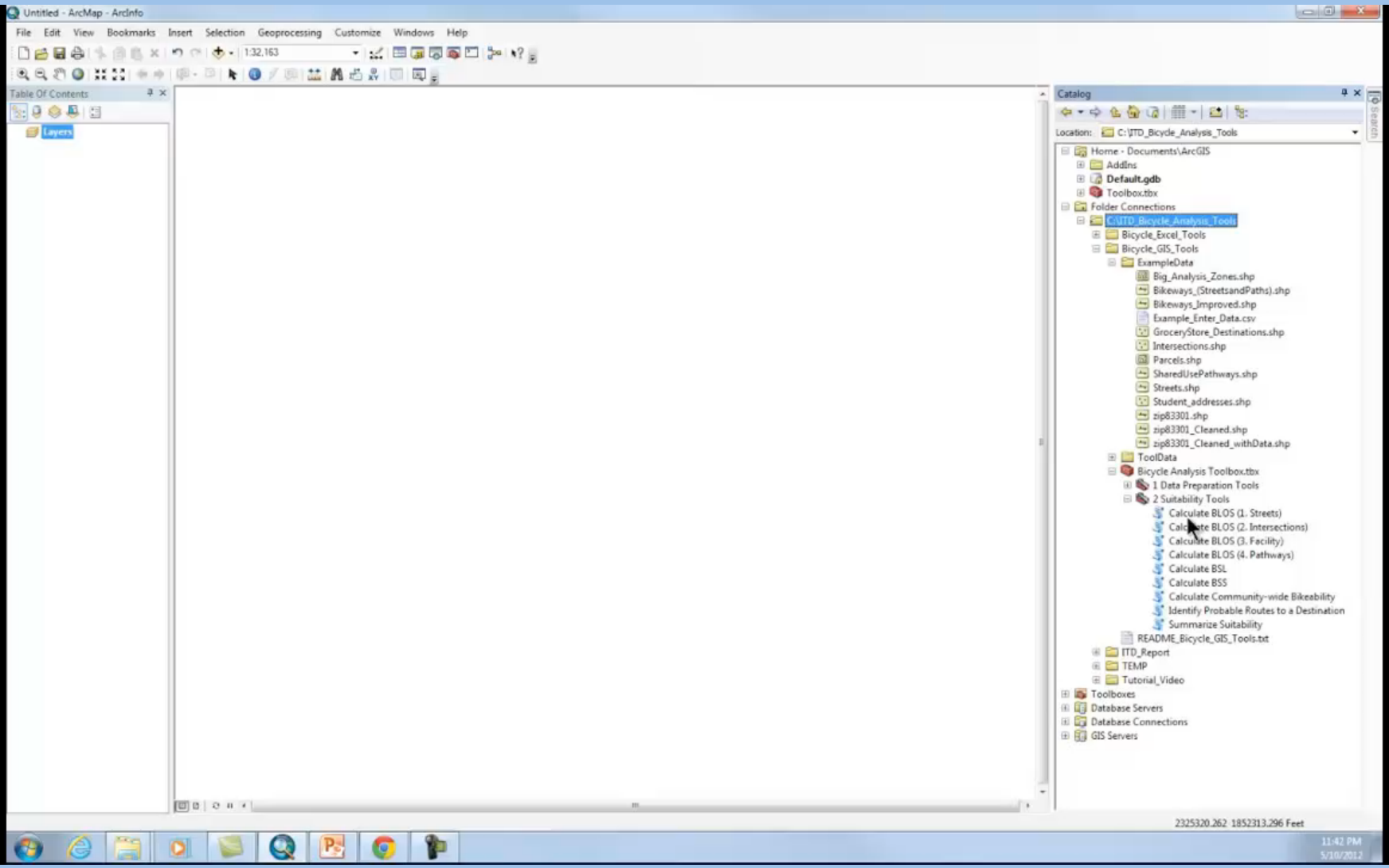
$$\frac{\text{AADT}}{\text{\# of thru Lanes} \times 2500} + \frac{\text{Speed (mph)}}{35} + \frac{14 - \text{Outside Lane Width} - \text{Bike Lane or Paved Shoulder Width}}{2} + \text{Pavement Factors} + \text{Location Factors} = \text{Bicycle Suitability Score}$$

$$\frac{16,500}{2 \times 2500} + \frac{35}{35} + \frac{14 - 12.5 - \text{Ø}}{2} + 1.75 + 2.75 = 9.6$$

[BLOS Demonstration video]

http://www.youtube.com/watch?v=k3ch1J9ugmM

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Layers
Catalog
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Home - Documents\ArcGIS
AddIns
Default.gdb
Toolbox.tbx
Folder Connections
C:\ITD_Bicycle_Analysis_Tools
Bicycle_Excel_Tools
Bicycle_GIS_Tools
ExampleData
Big_Analysis_Zones.shp
Bikeways_(StreetsandPaths).shp
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zip83301_Cleaned.shp
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ToolData
Bicycle Analysis Toolbox.tbx
1 Data Preparation Tools
2 Suitability Tools
Calculate BLOS (1. Streets)
Calculate BLOS (2. Intersections)
Calculate BLOS (3. Facility)
Calculate BLOS (4. Pathways)
Calculate BSL
Calculate BSS
Calculate Community-wide Bikeability
Identify Probable Routes to a Destination
Summarize Suitability
README_Bicycle_GIS_Tools.txt
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Tutorial_Video
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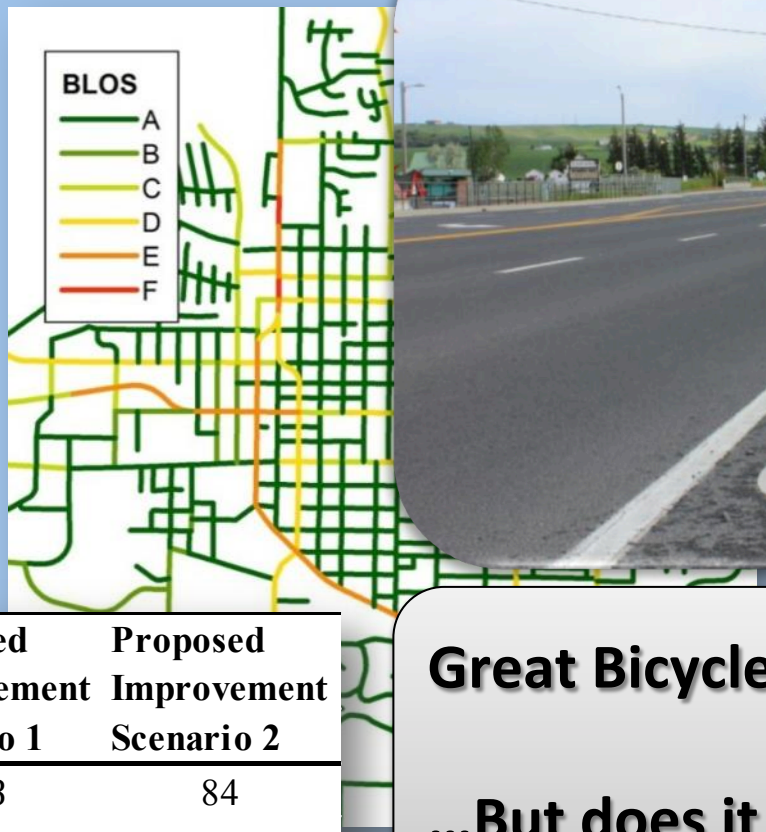


BLOS	Current Conditions	Proposed Improvement Scenario 1	Proposed Improvement Scenario 2
A	70	78	84
B	7	8	5
C	10	8	5
D	7	3	3
E	3	1	1
F	3	2	2

Great Bicycle Suitability…

…But does it go anywhere?

Tool 2

CALCULATE COMMUNITY-WIDE BIKEABILITY

- **Bicycle Suitability**

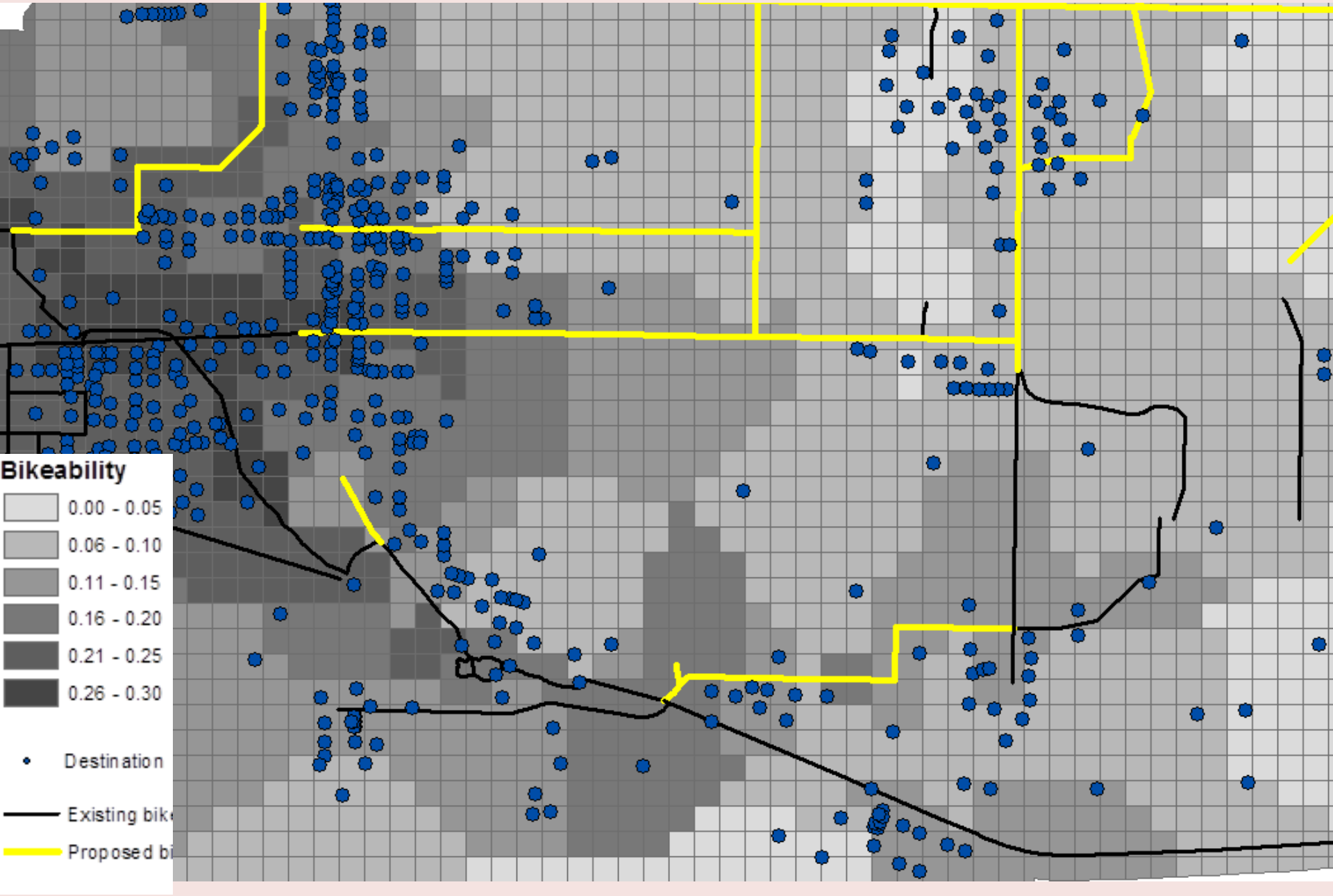
  Perceived comfort and safety of a segment of street or pathway

- **Bikeability**

  Perceived comfort and safety of network connectivity for accessing important destinations

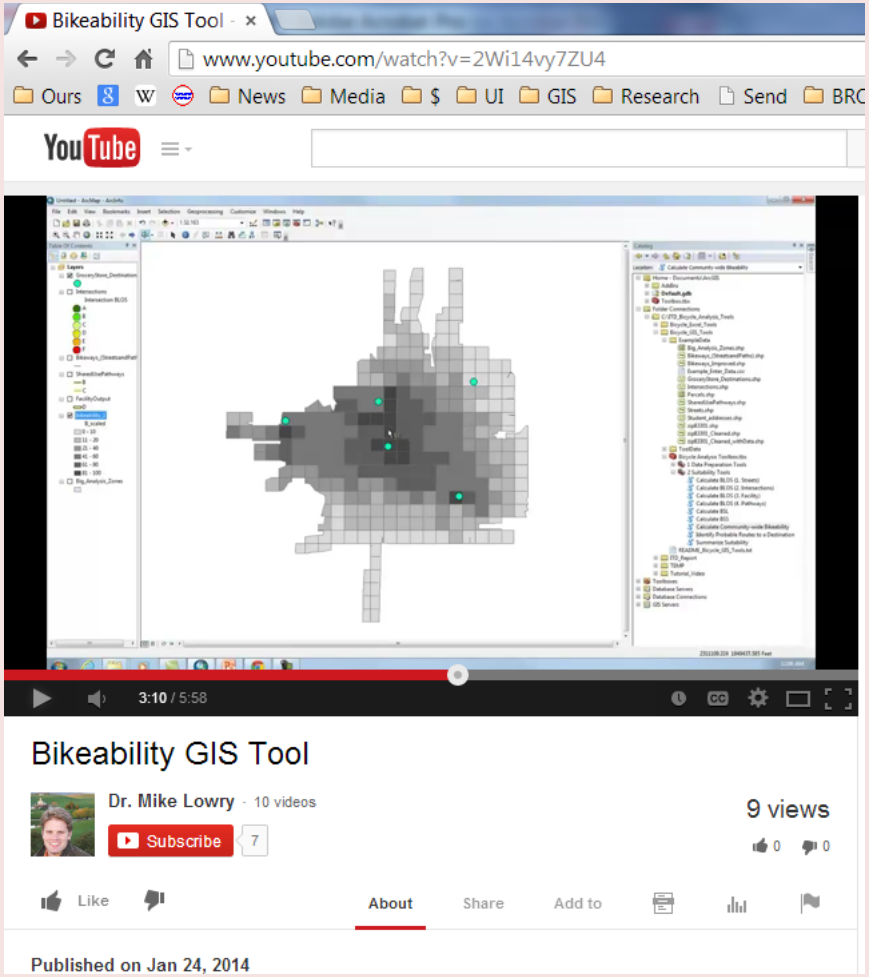
- **Bicycle Friendliness**

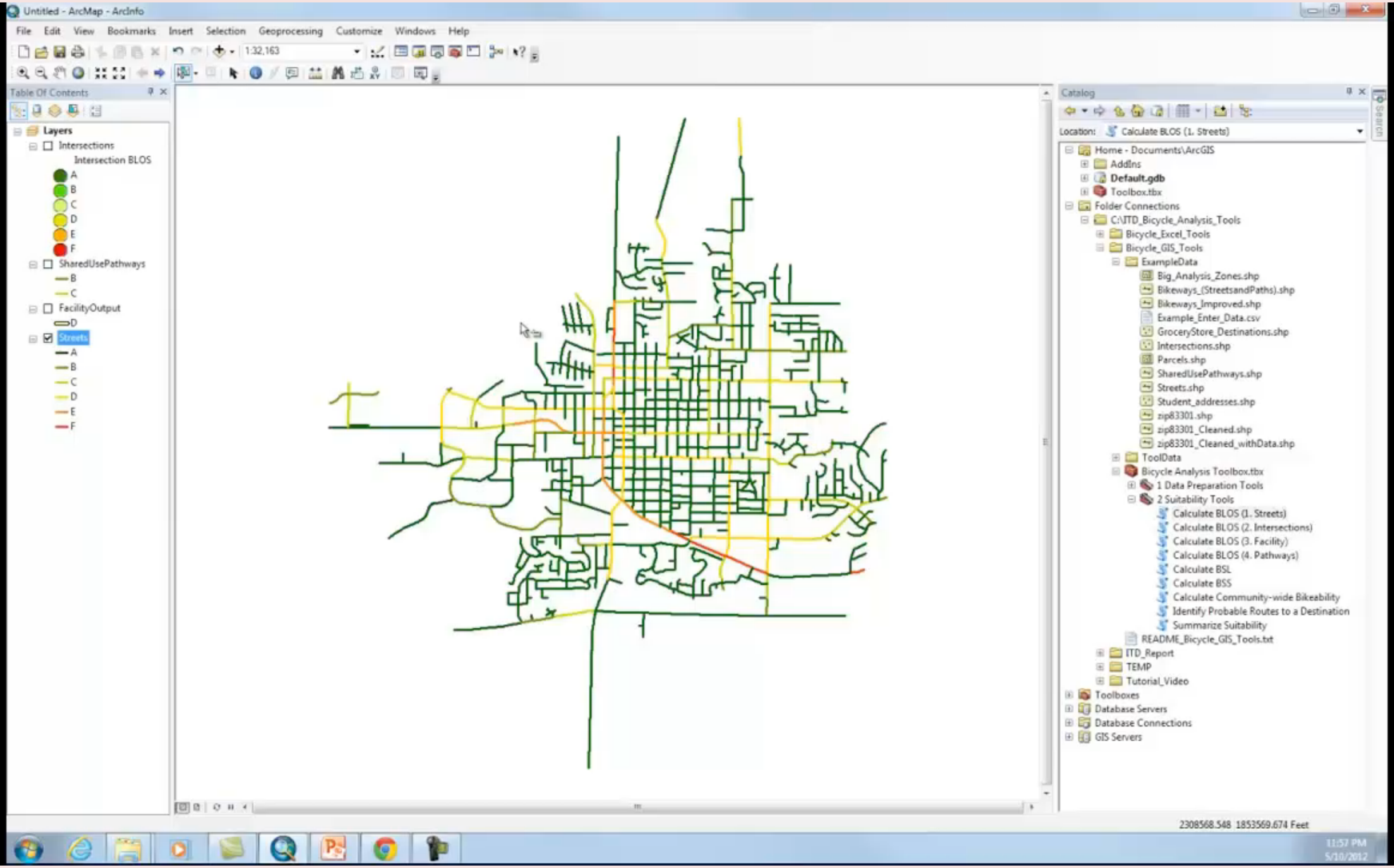
  Perceived comfort and safety of all aspects of bicycle travel, including bikeability, laws and policies to promote bicycling, education efforts to encourage bicycling, and general acceptance of bicycling throughout the community


Bikeability
0.00 - 0.05
0.06 - 0.10
0.11 - 0.15
0.16 - 0.20
0.21 - 0.25
0.26 - 0.30
Destination
Existing bik
Proposed bi

[Bikeability Demonstration video]

http://www.youtube.com/watch?v=2Wi14vy7ZU4

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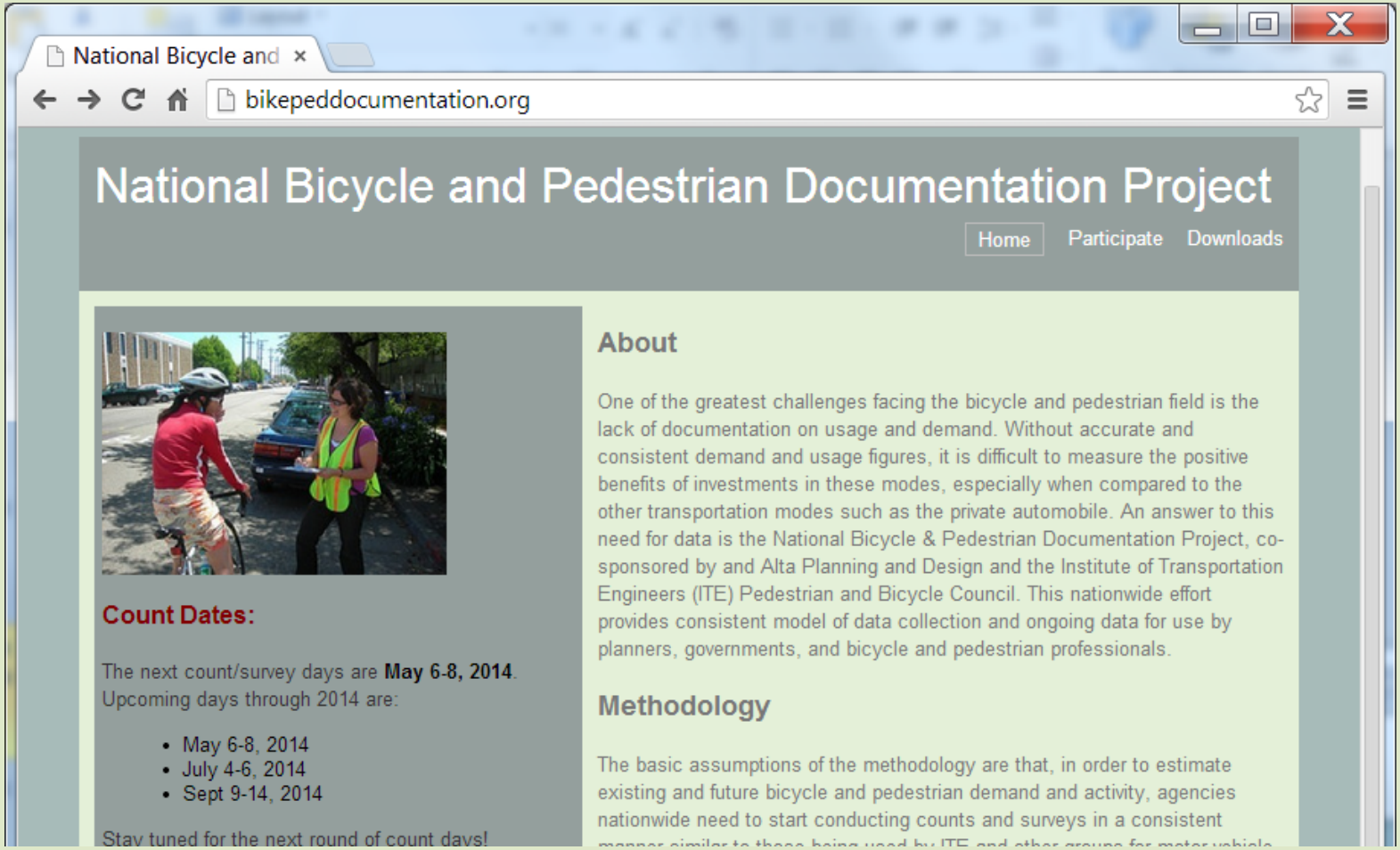
Tool 3

ESTIMATE BICYCLE VOLUMES

Background

Citizen-volunteer count programs



Instructions

The other dates were selected to provide a representative sampling of activity during a typical spring (May) and winter (January) period. The 4th of July period was selected because it will afford both a typical summer weekday and what is typically the busiest holiday period and activity period for recreational facilities and activities.

Having an official count week is also important for generating enthusiasm around the date. Much like nationwide Bike to Work Weeks, we hope that the National Documentation Project Week in September will become a much-anticipated annual event in localities around the nation.

Times

Based on our research, we are recomme
below). However, if you have been doin
using these same time periods for all fut

RECOMMEN
Weekday, 5-
Saturday, 12

SECONDARY
Weekday, 7
Saturday, 7 A

Rationale for Time Periods

Time periods are more important for co
periods were chosen since the afternoo
travelers, with commuters, school childr
conducted during these periods will pro
bicycling during the peak periods of the
peak period. Actual local peak periods n
that the national count time periods be
periods if it is determined that this perio

Automatic Machines

While the NBPD is based on manual cou
conducting counts to consider conductin
community. These machines will give in
usage, benefits and other information.

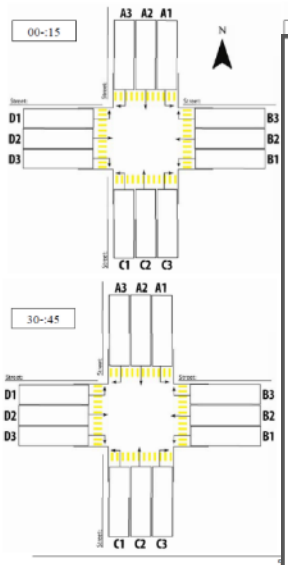
Weather

Weather may be a determinant in select
conduct counts and surveys, but a partic
poor or unusual during the count period

Forms

Please fill in your name, count location, date, time period, and weather conditions (fair, rainy, very cold).
Count all bicyclists crossing through the intersection under the appropriate categories.

- Count for two hours in 15-minute increments.
- Count bicyclists who ride on the sidewalk.
- Count the number of people on the bicycle, not the number of bicycles.
- Use one intersection graphic per 15-minute interval.



Training Presentation

How do you count this?

alta PLANNING + DESIGN

estrian Documentation Project
Home Participate Downloads
rials

Citizen Volunteer Counts

2012 Washington State Bicycle and Pedestrian Documentation Project

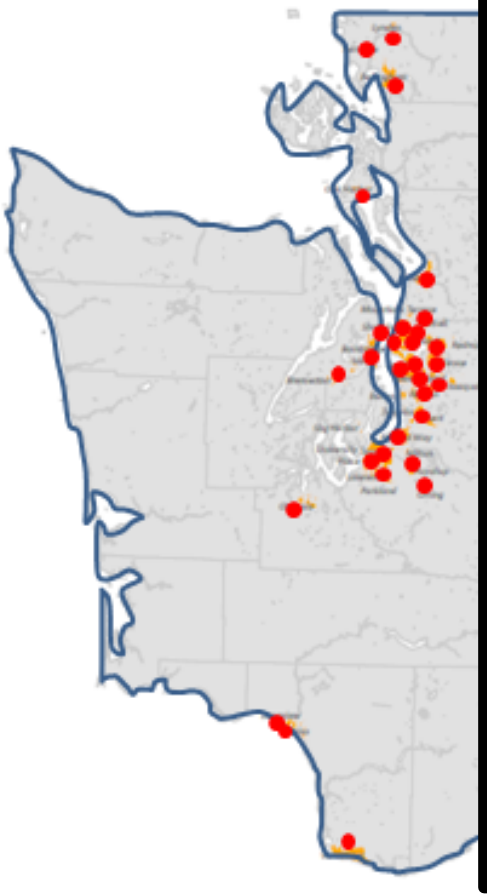


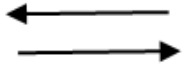
Table 2: Count cities and locations by year

City	2008 AM	2008 PM	2009 AM	2009 PM	2010 AM	2010 PM	2011 AM	2011 PM	2012 AM	2012 PM
Bainbridge Island	0	0	0	0	0	5	1	1	5	4
Bellevue	4	3	13	13	13	13	5	7	7	8
Bellingham	6	6	12	12	17	17	18	18	18	18
Bothell	5	6	6	4	6	3	6	5	6	5
Bremerton	6	6	6	4	6	5	1	3	6	5
Burien	0	0	4	9	9	9	9	9	10	10
Ellensburg	6	4	5	4	2	3	3	5	4	4
Everett	6	6	9	9	8	5	10	9	11	11
Federal Way	0	0	0	0	0	0	0	0	1	5
Ferndale	1	1	0	0	1	0	0	0	0	0
Gig Harbor	0	0	0	0	0	0	0	0	1	1
Issaquah	0	0	6	4	7	3	6	3	6	6
Kelso	0	0	5	7	8	8	0	1	2	0

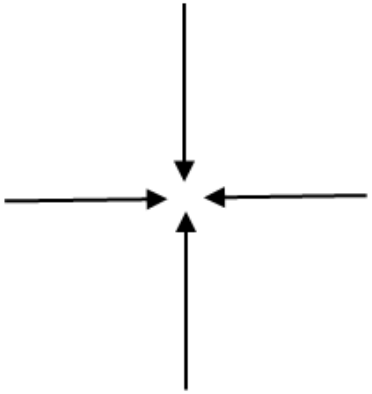
Table 2: Count cities and locations by year

City	2008 AM	2008 PM	2009 AM	2009 PM	2010 AM	2010 PM	2011 AM	2011 PM	2012 AM	2012 PM
Bainbridge Island	0	0	0	0	0	5	1	1	5	4
Bellevue	4	3	13	13	13	13	5	7	7	8
Bellingham	6	6	12	12	17	17	18	18	18	18
Yakima	3	3	1	1	1	2	2	3	1	1
Total	91	92	152	149	184	182	191	176	202	207
	183		301		366		367		409	

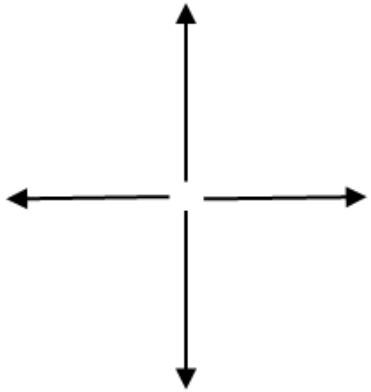
2 Movement
Screenline



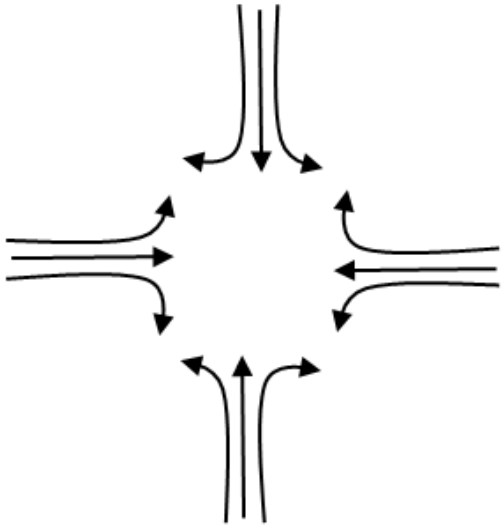
4 Movement
Toward Intersection



4 Movement
Leaving Intersection

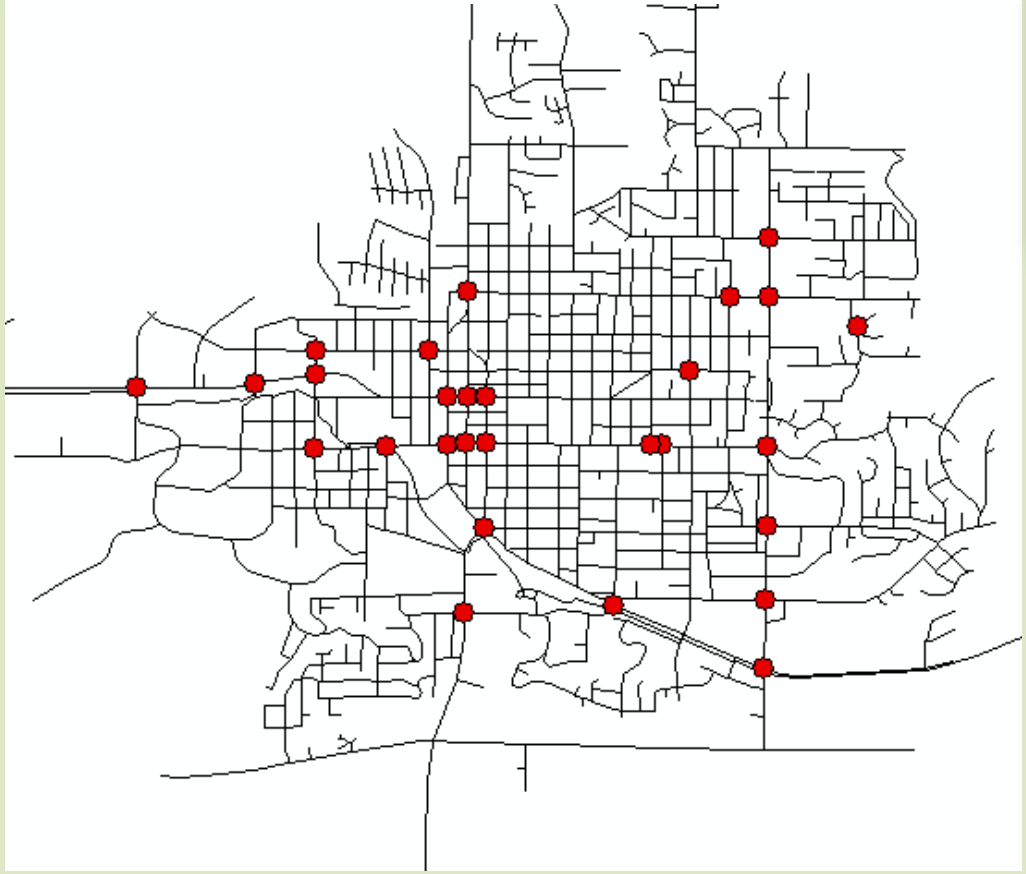


12 Movement



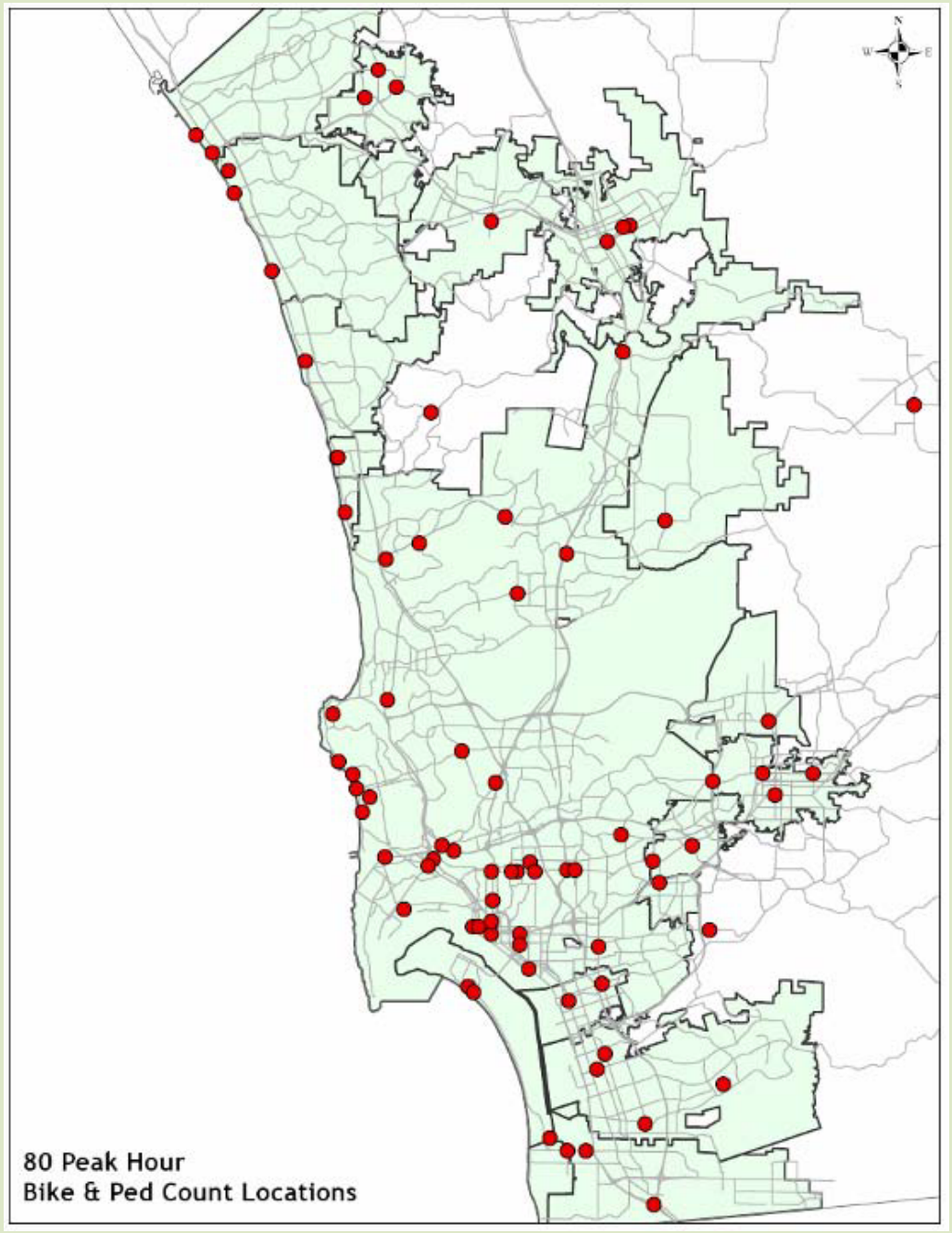
How can citizen-volunteer count data be used?

Snap shot of volumes



- 26 Locations
- 2011, 2012, 2013
- 7:00 – 9:00 AM
- 4:00 – 6:00 PM

80 locations!



Background

Estimating Bicycle Demand

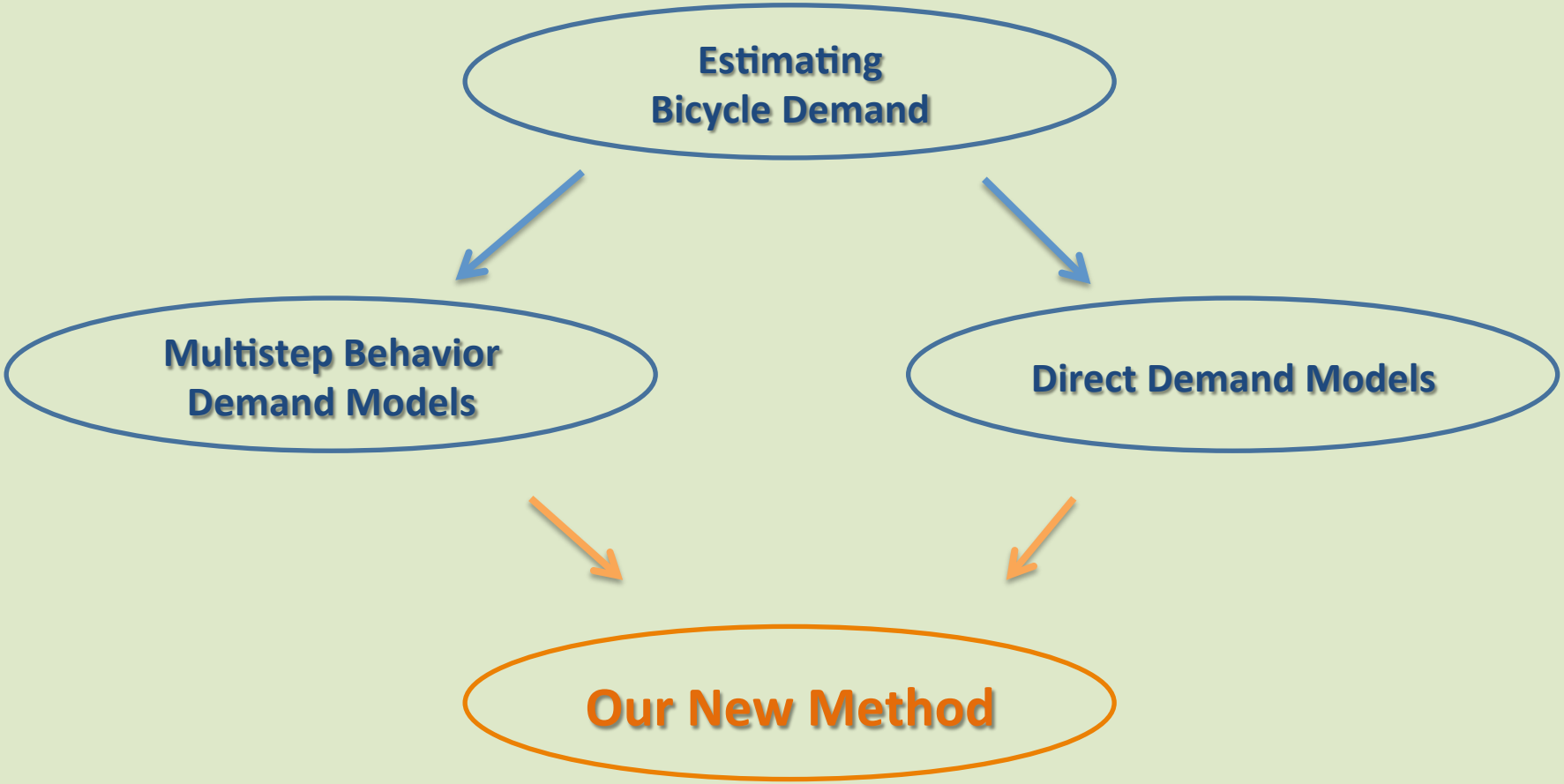
Multistep Behavior Demand Models

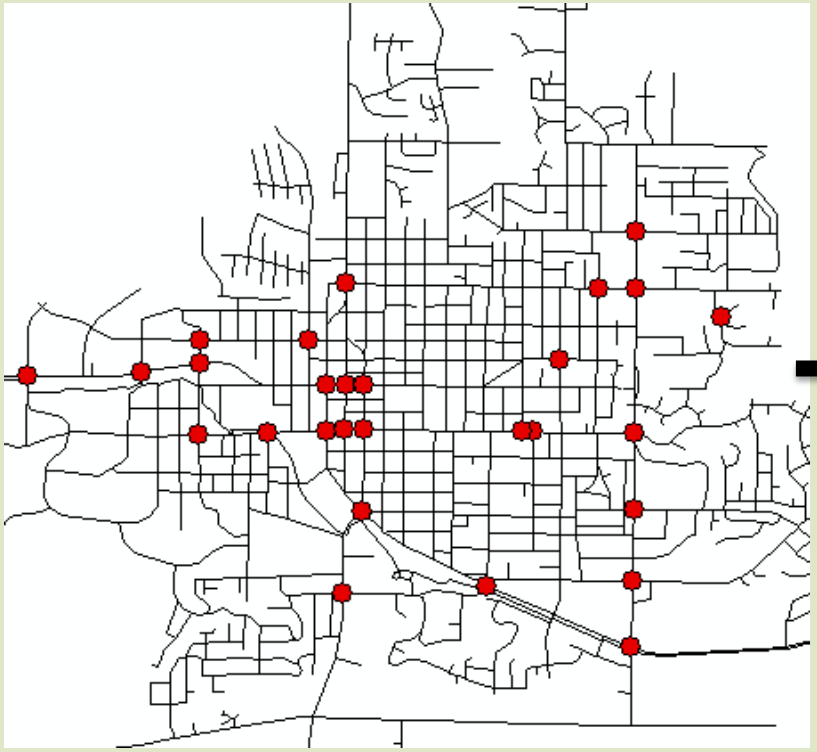
1. Trip generation
2. Trip distribution
3. Mode choice
4. Route assignment

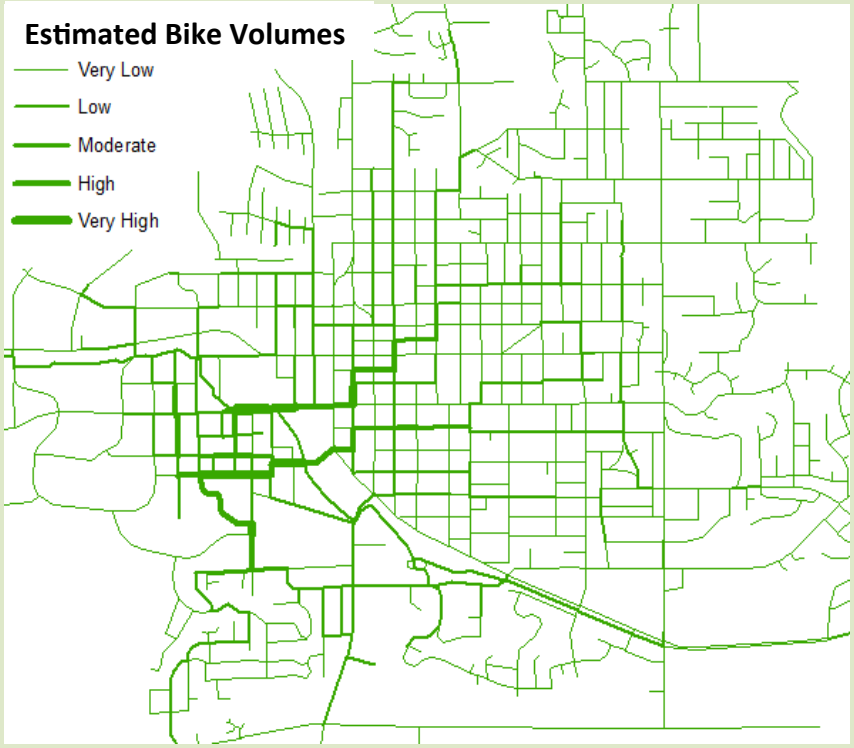
Direct Demand Models

Volume = β_0
+ β_1(Functional class)
+ β_2(Adjacent land use)
+ β_3(Distance to BART)

Background


Estimating
Bicycle Demand
Multistep Behavior
Demand Models
Direct Demand Models
Our New Method

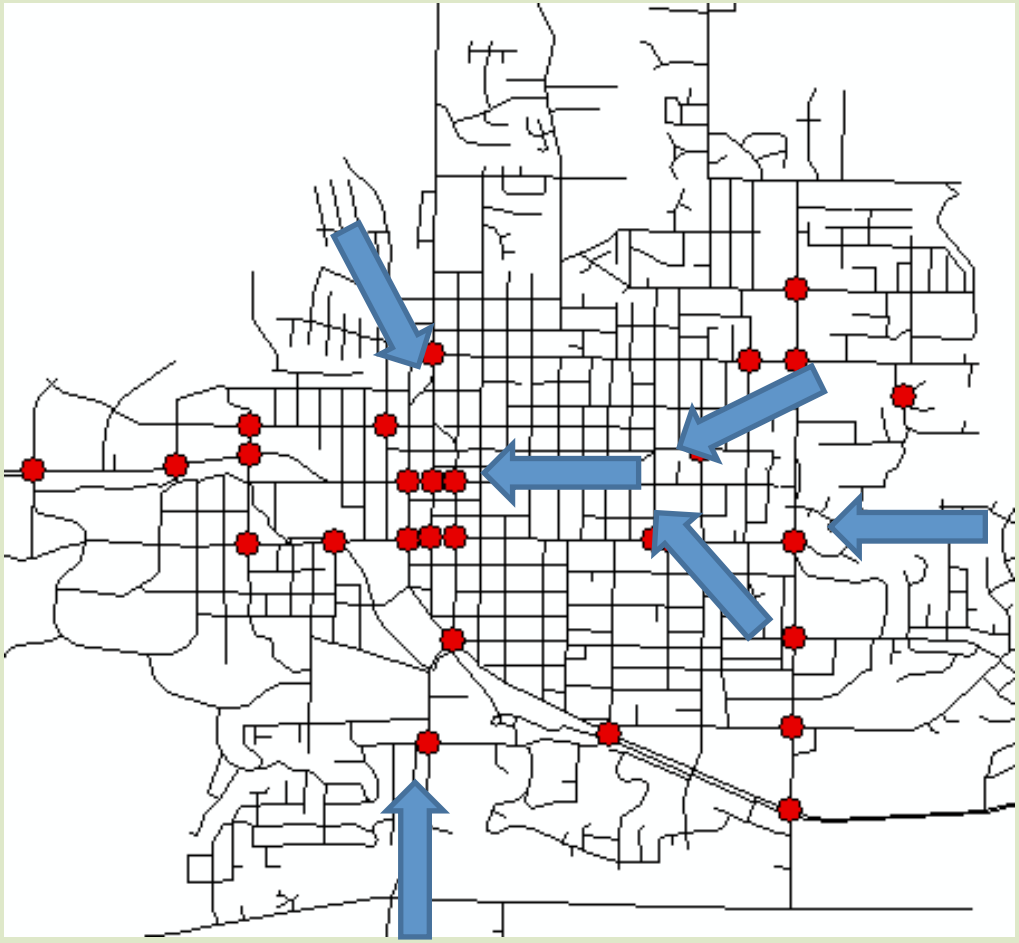




Observed Count Points

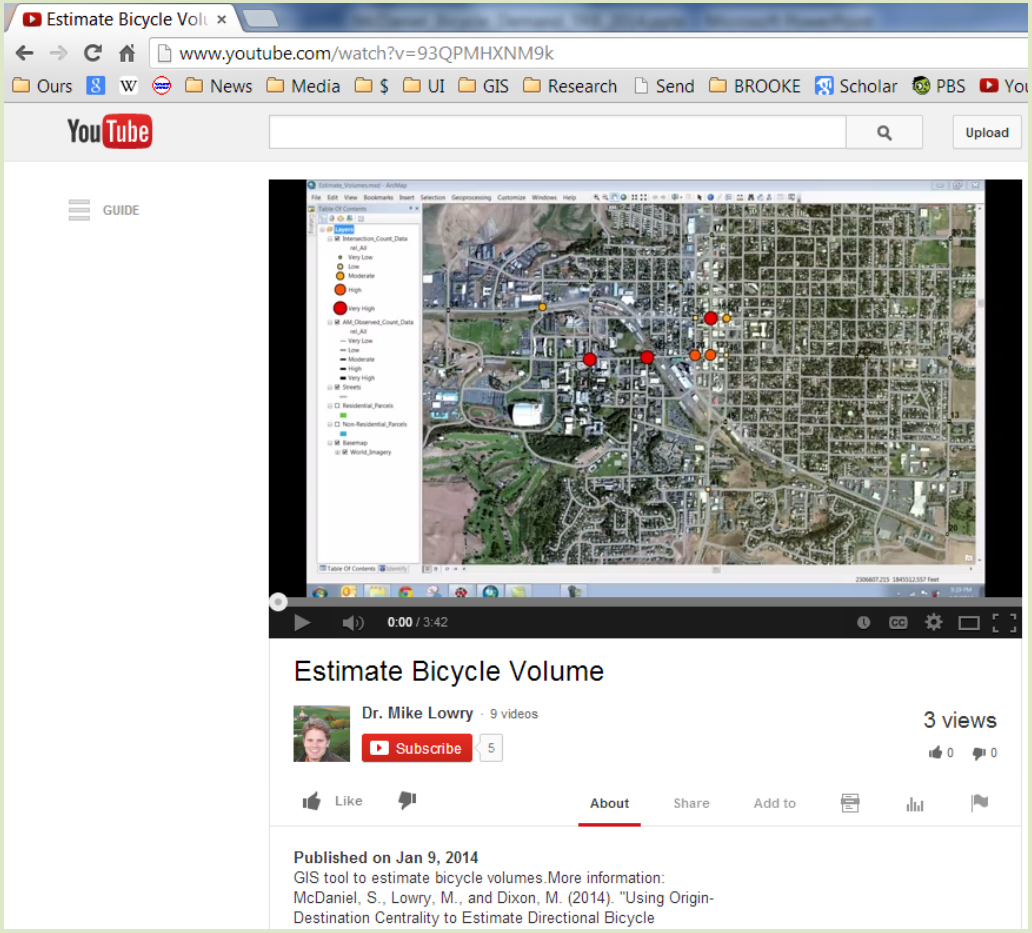
Network-wide 2 Hour Volume

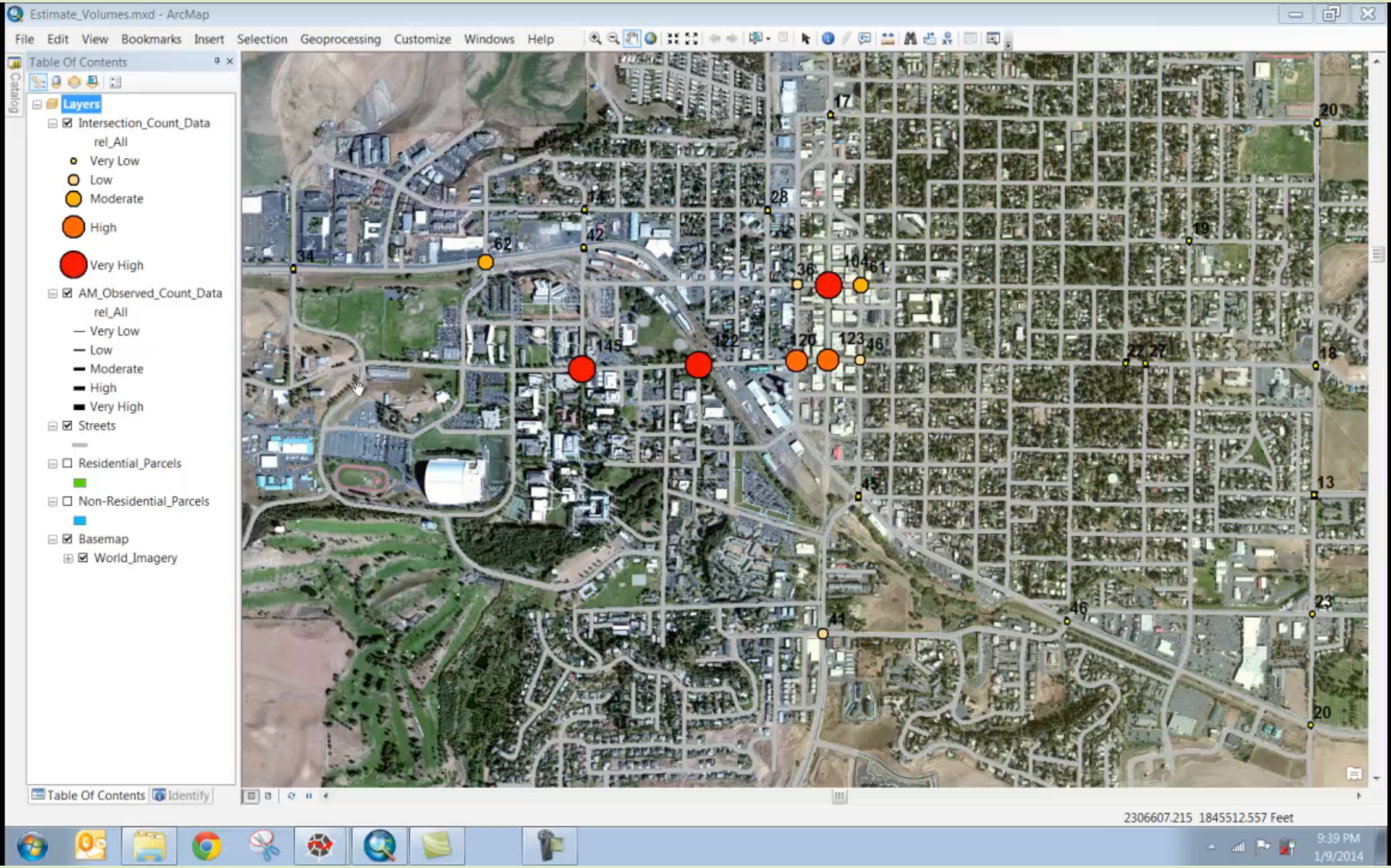
Topological Flow



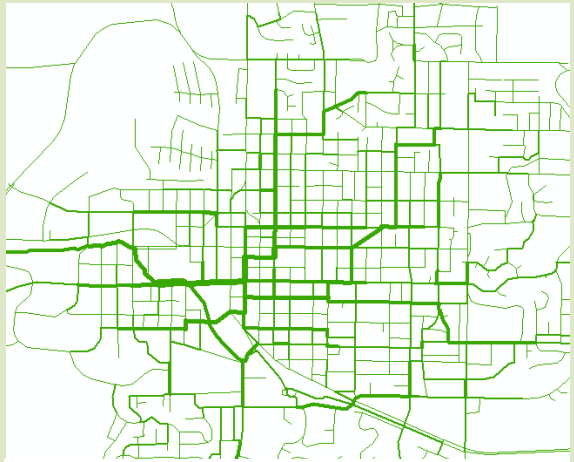
[Volume Estimation Demonstration video]

http://www.youtube.com/watch?v=dMp2XIQaykw

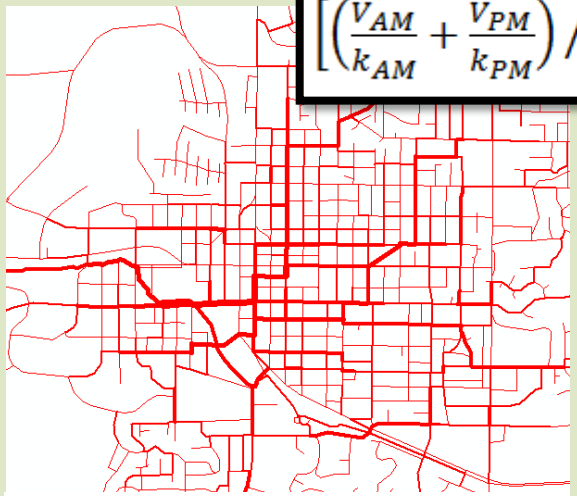



Estimate_Volumes.mxd - ArcMap
File Edit View Bookmarks Insert Selection Geoprocessing Customize Windows Help
Table Of Contents
Layers
Intersection_Count_Data
rel_All
Very Low
Low
Moderate
High
Very High
AM_Observed_Count_Data
rel_All
Very Low
Low
Moderate
High
Very High
Streets
Residential_Parcels
Non-Residential_Parcels
Basemap
World_Imagery
Table Of Contents
Identify
2306607.215 1845512.557 Feet
9:39 PM
1/9/2014

Step 1. Spatially Extrapolate



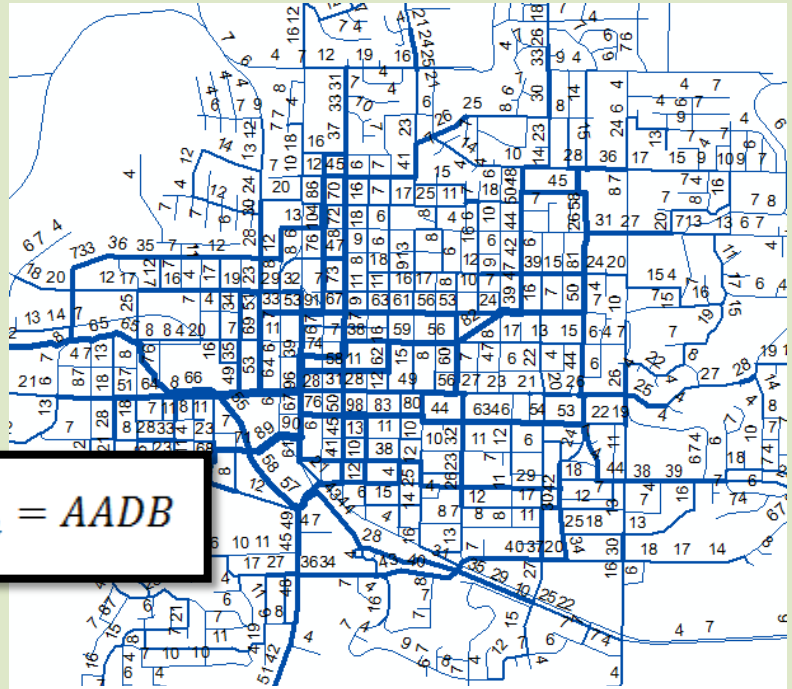
AM 2 Hour Volume



PM 2 Hour Volume

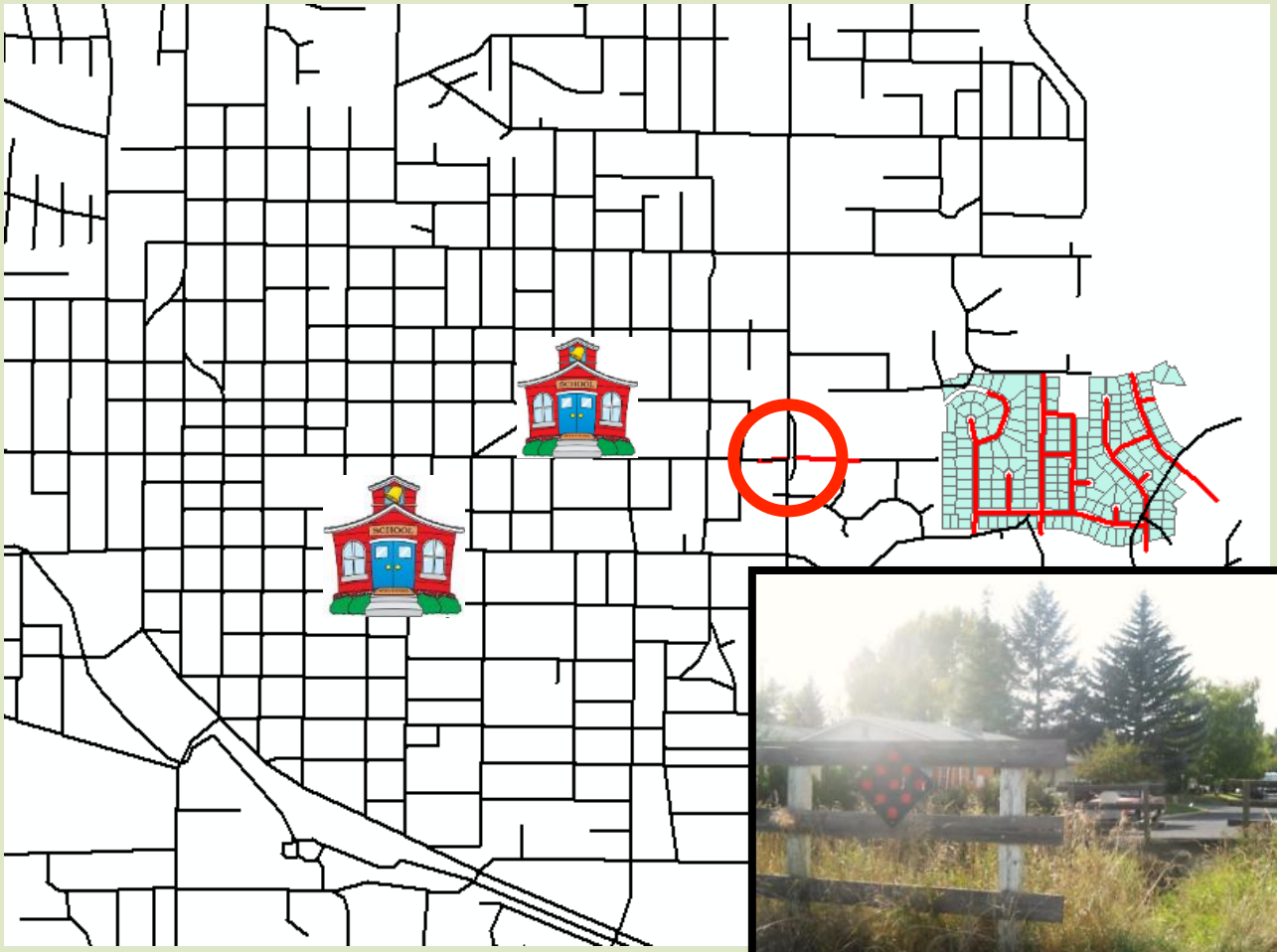
$$\left[\left(\frac{V_{AM}}{k_{AM}} + \frac{V_{PM}}{k_{PM}}\right)/2\right] * F_{day} * F_{month} = AADB$$

Step 2. Temporally Extrapolate



AADB

Scenario Planning



Scenario Planning

Third Street Bicycle Volumes Existing and Forecasted

Intersection Cross Street	Existing Conditions (AADB)	Proposed Scenario (AADB)
Van Buren Street	24	226
Harrison Street	28	230
Tyler Street	32	230
Polk Street	44	253
Taylor Street	89	239
Fillmore Street	127	255
Pierce Street	146	255

Increase of about 200 bicyclists per day.

Increase of about 150 bicyclists per day.

Tool 4

ASSESS DANGEROUS SITUATION EXPOSURE

Background

Challenge of Accident Analysis

1. Lack of Volume Data
2. Lack of Accident Data

Dangerous Situations
(Situational Antecedents to accidents)

Dangerous Situation	Description	References
Mixed cycling in harsh traffic	Cycling in the vehicle travel lane on a road with high vehicle volume, speed, and/or percent heavy vehicle	Mapes, 2009; Teschke, 2012; Harkey and Stewart, 1997; Elvik et al., 2009; Moritz 1997; Tinsworth et al., 1994; Allen-Munley et al., 2004; Klop and Khattak, 1999; Vandenbulcke 2013; Schepers et al., 2013; CROW 2007; Kim et al., 2007; Stone and Broughton, 2003; Carter et al., 2007; McCarthy and Gilbert, 1996
Dedicated ROW in harsh traffic	Cycling in a dedicated right-of-way adjacent to high vehicle volume, speed, and/or percent heavy vehicle	Reynolds et al., 2009; Pucher and Buehler, 2012.
Separated cycling	Physically separated on-street cycling, such as cycle tracks	Lusk et al., 2011; Lusk et al., 2013; Kin et al., 2007; Wachtel and Lewiston, 1994; Schepers et al., 2011
Cramped Space	Roads without a bike lane or shoulder, narrow travel lanes	McCarthy and Gilbert, 1996; Vandenbulcke 2011; Allen-Munley et al., 2004; Klop and Khattak, 1999; Harkey and Stewart, 1997
Excessive space	Roads with wide travel lanes, no bike lane, and at least moderate speed	Allen-Munley et al., 2004; Hunter et al., 1999
Dooring and vehicle parking	Areas with on-street parking and high parking turnover	Vandenbulcke et al., 2013; Tilahun et al., 2007
Frequent access points	High frequency of driveways	Allen-Munley et al., 2004; Emery and Crump, 2003

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Dangerous Situations

Dangerous Situation	Description	References
Crossing harsh traffic	Crossing a road with high vehicle volume, speed, and/or percentage heavy vehicle	Summala et al., 1996; CROW, 2007; Schepers et al., 2011
Complicated intersections	Navigating; e.g. five point intersections or roundabouts	Daniels et al., 2009; Brüde and Larsson, 2000; Schoon and Van Minnen, 1994; Vandenbulcke et al., 2013
Right hook	Right-turning cars conflicting with through cyclist	McCarthy and Gilbert, 1996; Räsänen and Summala, 1998; Schimek, 2014; Weigand, 2008; Schepers et al., 2013; Furth et al., 2014
Left sneak	Cyclist sneaking across travel lanes to complete a left turn	Hunter et al., 1999
Thru clip	Left turning vehicles conflict with through cyclist	Summala et al., 1996; Räsänen and Summala, 1998; Schimek, 2014; Shepers et al., 2014
Gaps in bicycle network	Discontinuity of bicycle the network	Krizek and Roland, 2005; Mekuria et al., 2012
Wrong-way riding	Cycling the wrong-way on a one-way street.	Wachtel and Lewiston, 1994; Räsänen and Summala, 1998; Schimek, 2014; Summala et al., 1996; Hunter et al., 1999;
Sidewalk riding	Cyclist utilizing sidewalks	Schimek, 2014; Wachtel and Lewiston 1994;
Infrequent cyclers	Low cyclist volume	Elvik et al., 2009; Jacobsen, 2003; Nordback et al., 2014; Brüde and Larsson, 1993; CROW 2007

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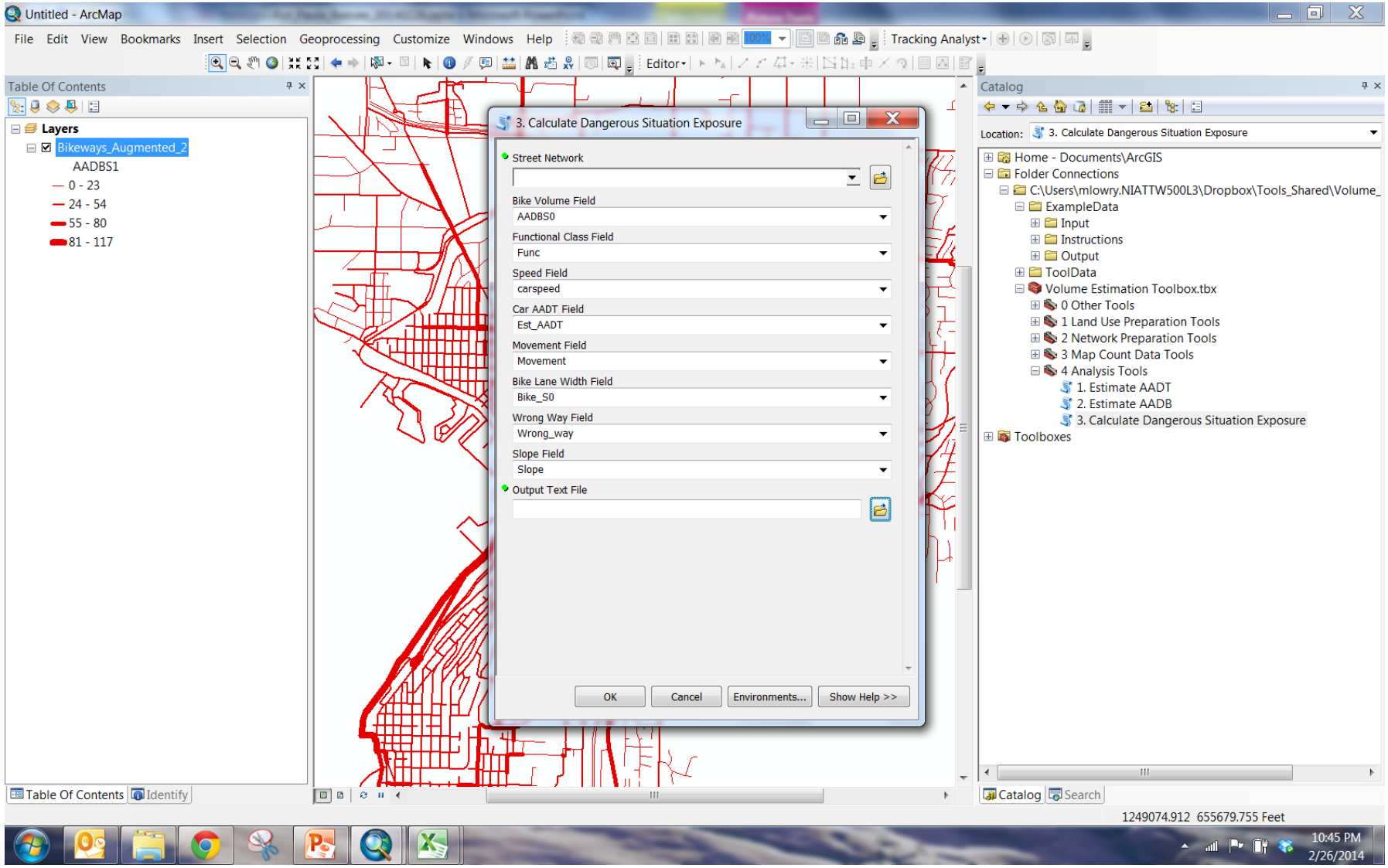
Step 1. Define Exposure Metrics

Dangerous Situation	Metric
Separated cycling in harsh traffic	Bike lane Vehicle volume > 8,000 AADT
Mixed cycling in harsh traffic	No bike lane Vehicle volume > 3,000 AADT
Cramped space	Vehicle lane width < 12 ft Vehicle volume > 1,000 AADT Vehicle speed limit > 20 mph
Parking maneuvers and dooring	Parking turnover > 4 maneuvers per hr
Frequent acces points	Access points > 30 per mile
Steep grade	Grade > 4%
Wrong-way riding	Wrong-way riding occurrence
Unexpected cyclers	Cyclist volume < 50 AADB

Community-specific metrics should be based on:

- **Public involvement**
- **Local experience**
- **Latest research**

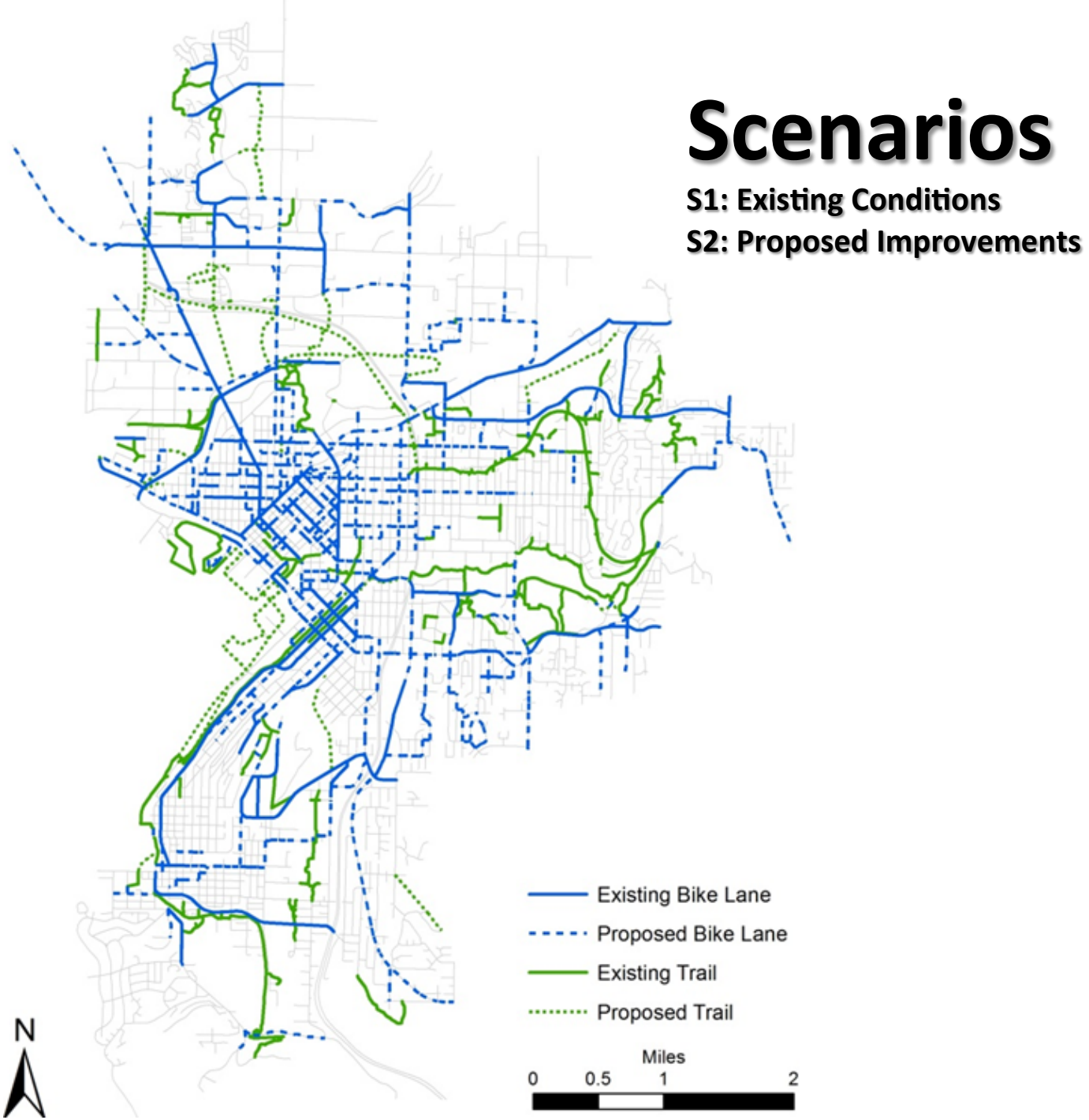
Step 2. Calculate Exposure



Scenarios

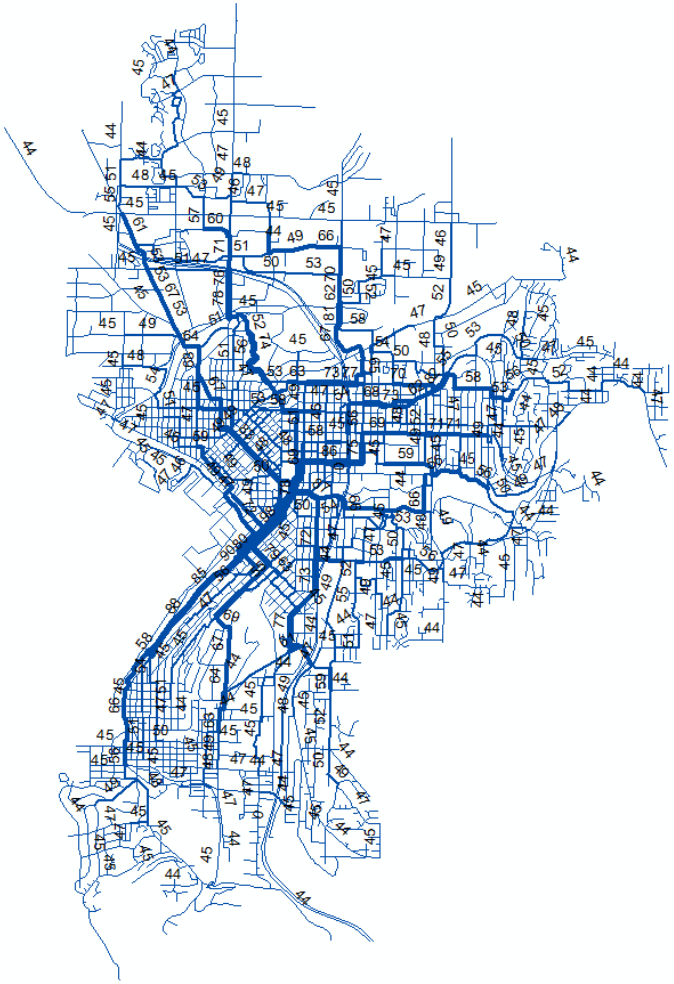
S1: Existing Conditions

S2: Proposed Improvements

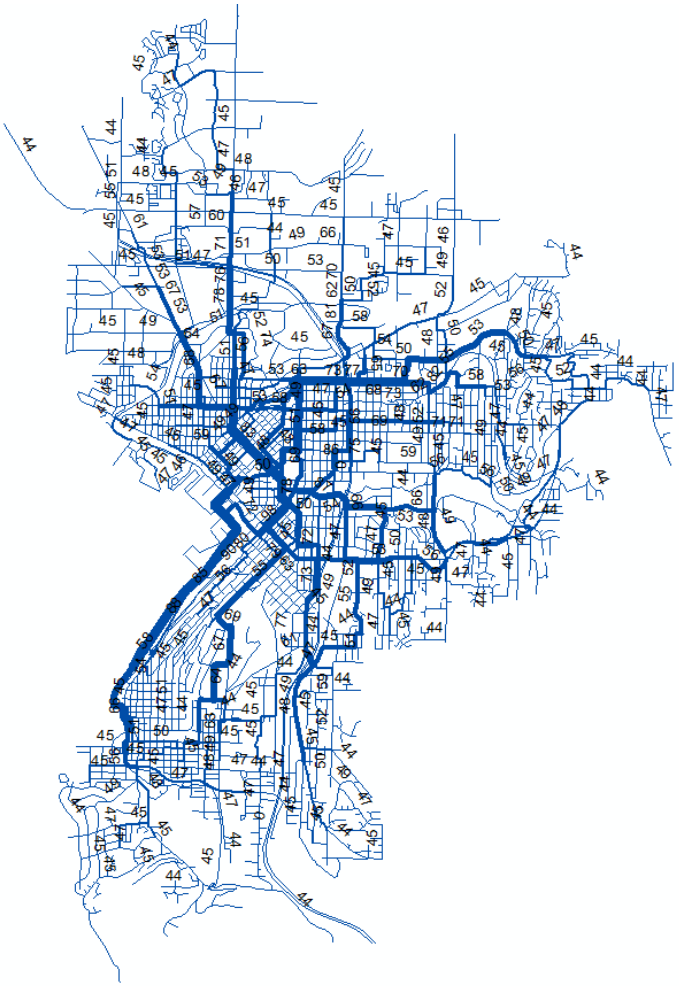


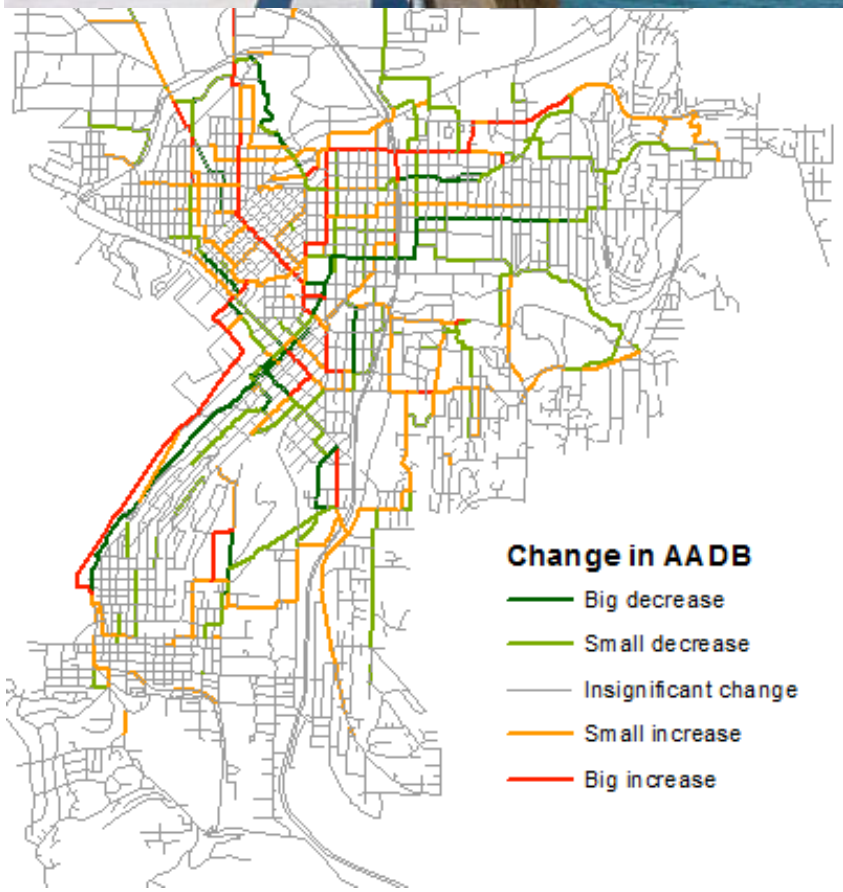
AADB

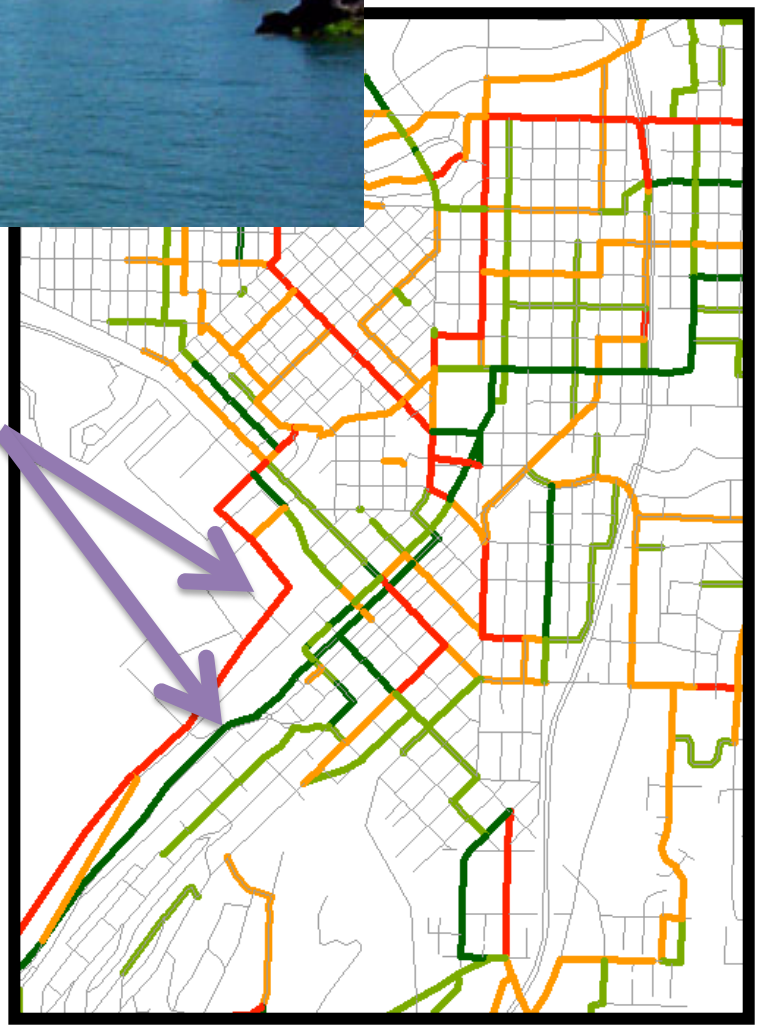
Scenario 1 (Existing)



Scenario 2 (Proposed)




Change in AADB
Big decrease
Small decrease
Insignificant change
Small increase
Big increase



Exposure Along Street Segments

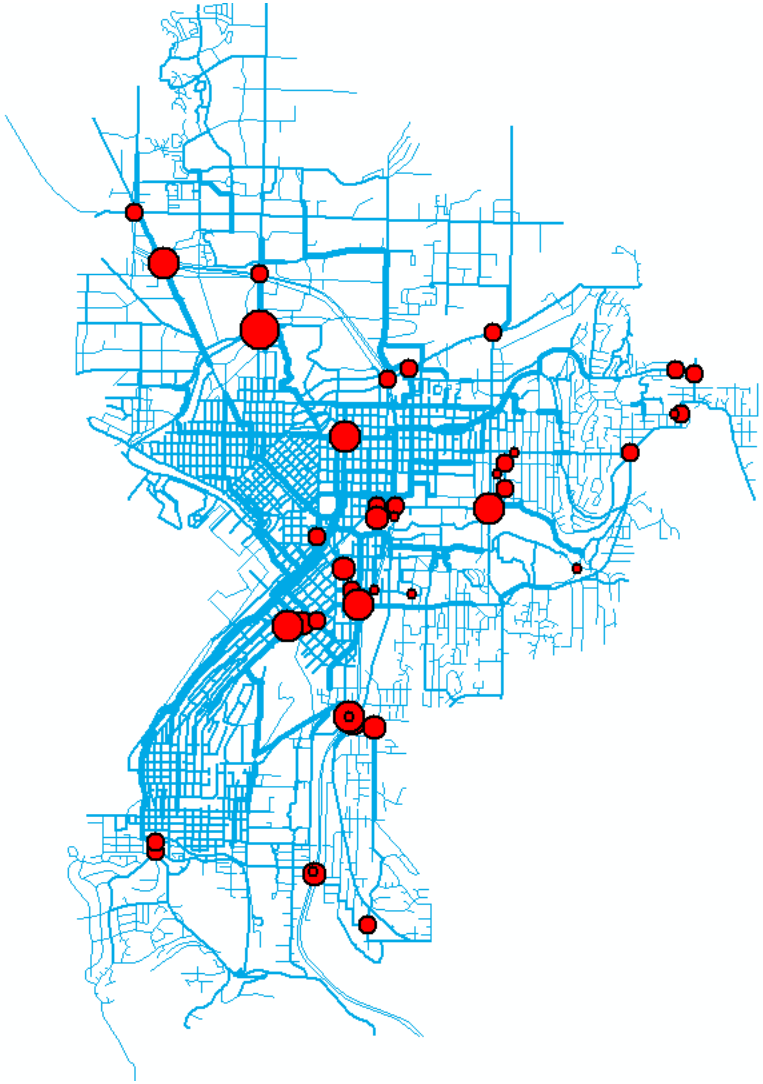
Dangerous Situation	Metric Conditions	Scenario 1: Existing Conditions (Annual BMT)	Scenario 2: w/ Proposed Improvements (Annual BMT)	Change (Annual BMT)	Percent Change
Mixed cycling in harsh traffic	No bike lane Vehicle volume > 3,000 AADT	666,000	272,000	-394,000	-59%
Dedicated ROW in harsh traffic	Bike lane Vehicle volume > 8,000 AADT	97,000	250,000	153,000	158%
Cramped space	Veh. lane width < 12 ft Vehicle volume > 1,000 AADT Vehicle speed limit > 20 mph	307,000	180,000	-127,000	-41%
Dooring and vehicle parking	Vehicle parking turnover > 4 per hr	2,646,000	2,746,000	100,000	4%
Frequent access points	Access points > 30 per mile	3,923,000	3,847,000	-76,000	-2%
Steep grade	Grade > 4%	197,000	197,000	0	0%
Wrong-way riding	Wrong-way riding occurrence	134,000	145,000	11,000	8%
Infrequent cyclers	Cyclist volume < 15 AADB	1,151,000	1,096,000	-55,000	-5%

Exposure at Intersections

Dangerous Situation	Metric Conditions	Scenario 1: Existing Conditions (Annual Bicyclists)	Scenario 2: w/Proposed Improvements (Annual Bicyclists)	Change (Annual Bicyclists)	Percent Change
Crossing harsh intersections	Cross street vehicle volume > 2,000 AADT	7,114,000	6,647,000	-467,000	-7%
Right hook	Vehicle right turns > 1,000 AADT	605,000	577,000	-28,000	-5%
Left sneak	Oncoming thru vehicle volume > 2,000 AADT	7,516,000	7,523,000	7,000	0%
Thru clip	Oncoming left-turn vehicle volume > 1,000 AADT	615,000	613,000	-2,000	0%

Hot Spot Analysis

Right Hook Exposure



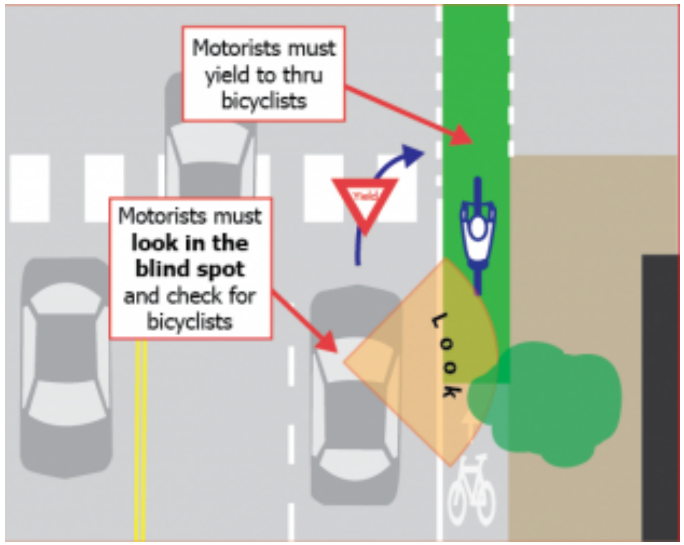
Future Work

1. Create Safety Performance Functions (SPFs) based on exposure.

Expected Number of Right Hook Accidents = $\beta_0 + \beta_1$(right hook exposure)

2. Create Crash Modification Factors (CMFs) to for improvements.

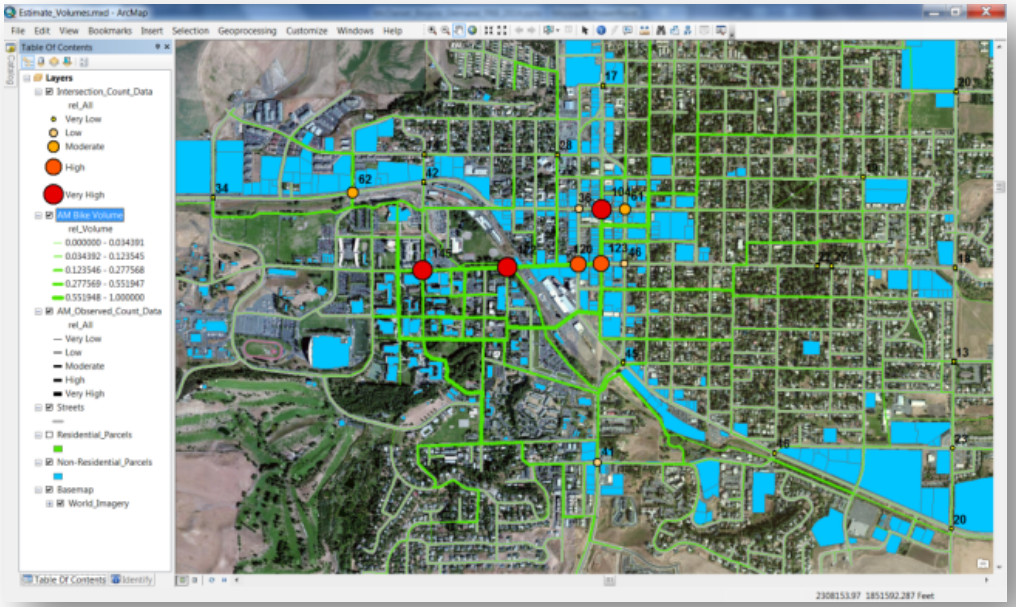
green paint => 12% reduction



Conclusions

New tools are…

- **Inexpensive and easy to use,**
- **Require commonly available GIS data, and**
- **Can produce very good results.**




Thank you…
…Questions??
Mike Lowry, PhD, PE
University of Idaho
(208) 885-0139
mlowry@uidaho.edu

Tool 1: Calculate Bicycle Level of Service

Callister, D. and Lowry, M. (2013). "Tools and Strategies for Wide-scale Bicycle Level of Service Analysis." ***ASCE Journal of Urban Planning and Development*****, Vol. 139, No.4, p. 1-8.**

Tool 2: Calculate Community-wide Bikeability

Lowry, M., Callister, D., Gresham, M. and Moore, B. (2012). "Assessment of Communitywide Bikeability with Bicycle Level of Service." ***Transportation Research Record: Journal of the Transportation Research Board*****, 2314, pp. 41-48.**

Tool 3: Estimate Bicycle Volumes

McDaniel, S., Lowry, M., and Dixon, M. (In press). "Using Origin-Destination Centrality to Estimate Directional Bicycle Volumes." ***Transportation Research Record: Journal of the Transportation Research Board*****, Scheduled publication 2014.**

Tool 4: Assess Dangerous Situation Exposure

Cool, S. and Lowry, M. (Forthcoming). "Quantifying dangerous situation exposure for bicyclists" Scheduled Submission June, 2014.